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of
Columbia University
Dobbs Ferry, New York

Alan Berman
Director

Hudson Laboratories of Columbia University
Technical Memorandum No. 73

Marine Physical Laboratory Technical Memorandum 150

DEEP-TOWED PROTON MAGNETOMETER

by

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1.1 INTRODUCTION

In February 1964 the author was requested to supply a proton magnetometer for incorporation in the Hudson Laboratories deep-towed system with a view to measuring the geomagnetic field near the ocean bottom. These measurements would be of use in interpretation of the structure of the ocean floor and also in Thresher-type searches. The equipment was required to work in conjunction with side-looking sonar and sub-bottom acoustic profiling systems (Clay et al. 1964).

The proton magnetometer only became operational after a week at sea owing to mechanically inadequate detector design and construction. No difficulty was experienced in multiplexing the various systems. The magnetometer worked satisfactorily apart from effects ascribable to the detector head failure. A new detector has since been designed which operated successfully at depths of 2000 fathoms. A description of the new design is included.

This memorandum describes the principles of operation of the system and the relevant circuitry. The memorandum discusses the equipment in detail sufficient to enable the magnetometer to be operated by personnel with no previous knowledge of proton magnetometers.

1.2 PREVIOUS WORK

A prototype deep-towed proton magnetometer system was tested successfully in shallow water at the Marine Physical Laboratory in the summer of 1962 for use in a program of detailed study of deep-sea fine scale topography (MPL interim status report 1962, p. 7). This equipment was used by Dr. J. C. Belshe in the search for the hull of the nuclear

submarine Thresher in 1962 (Belshé, in preparation). Two other proton magnetometer systems were developed: one by Lamont Geological Observatory (Cottone 1963) and the other by Varian Associates, Naval Oceanographic Office and Naval Research Laboratories (Carrolland Walczak 1964, Varian Associates 1963).

Owing to the lack of time, none of the original search instruments were designed to work in conjunction with other types of equipment, e.g., cameras, radiation detectors, side-looking sonar. The usual difficulty of navigation at sea, therefore, prevented positive correlations being made between bottom features and magnetic anomalies. It was therefore decided to develop a mutually compatible magnetometer side-looking sonar system, and this report describes the magnetometer aspect of the combined system, as shown in Fig. 1.

2.1 PRINCIPLES OF OPERATION

The principles of operation and construction of proton magnetometers are well documented: Packard and Varian (1954), Waters and Francis (1958), Hill (1959), Aitken (1961), Warren and Vacquier (1961), Bullard and Mason (1963), and Mudie and Belshé (1964). Only a brief account of the method will be given here.

Protons possess a nuclear magnetic moment, μ, in addition to angular momentum; $I\hbar$; these are related by the gyromagnetic ratio

$$\mu = \gamma I \hbar .$$

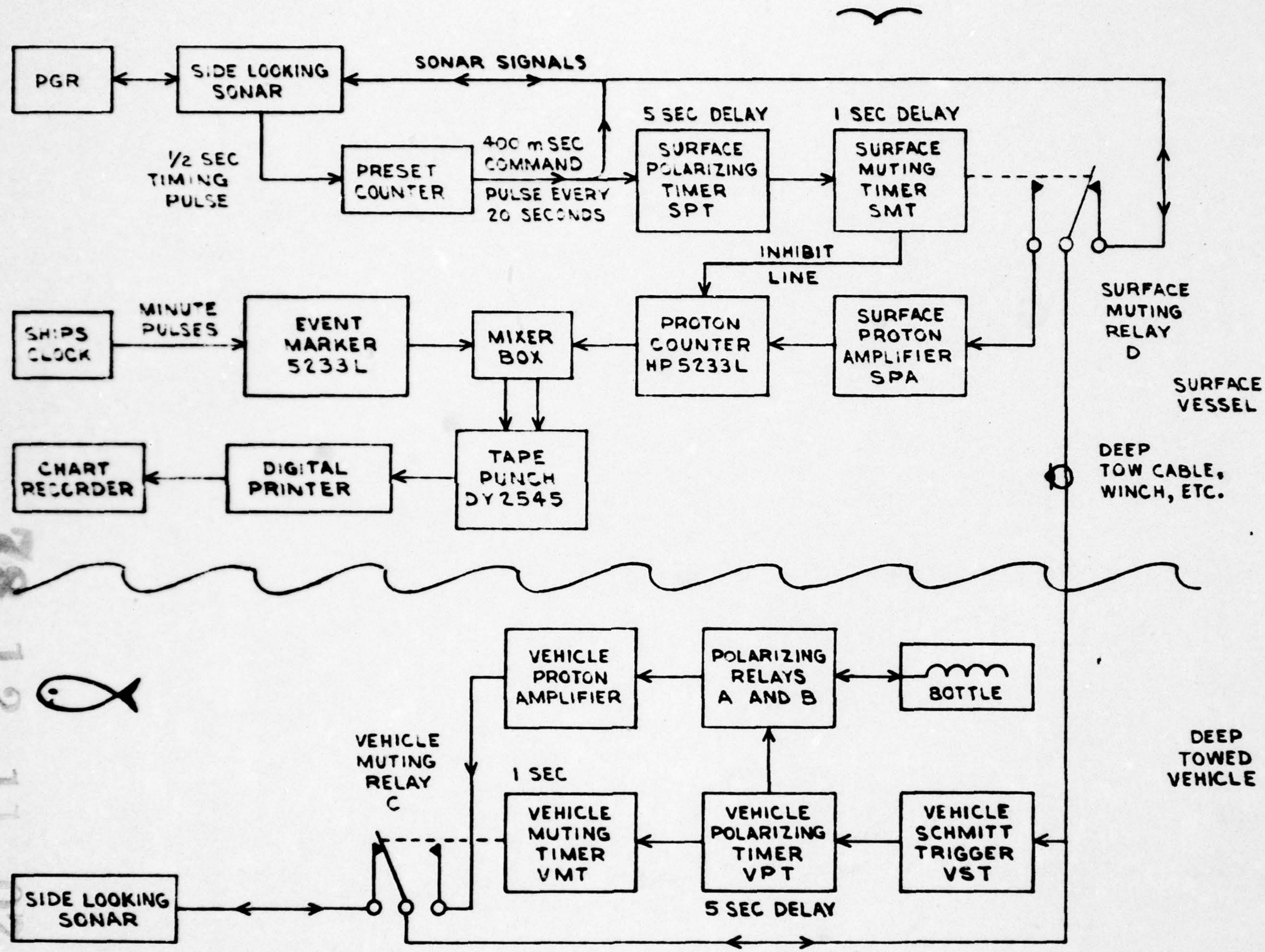


Fig. 1 SYSTEM BLOCK DIAGRAM

In operation a proton-rich sample, i.e., water, is placed in the center of a coil (aligned approximately at right angles to the earth's magnetic field) and a current passed through the coil introducing a high field (c. 100 oersteds). This field aligns the spin axes preferentially (polarizes) by coupling with the nuclear dipole moment. After 5 sec the polarizing field is removed and the protons precess about the geomagnetic field. The angular frequency of precession

$$\omega = \frac{\mu H}{I \hbar}$$

$$= \gamma H$$

where $\gamma = 2.67513 \times 10^4$ oersted per second (Nelson, 1960) and H is the magnitude (intensity) of the geomagnetic field. Thus a precise measurement of the frequency of precession of the protons enables one to determine the magnitude of the magnetic field.

The precessing proton dipole moments set up a rotating magnetic field which induces an emf in the polarizing coil. If the polarizing field is removed sufficiently quickly (Bullard, Mason, and Mudie, 1964), the amplitude of the proton signal is proportional to $\sin^2 \alpha$ where α is the angle between the coil axis and the earth's magnetic field. Hence, for maximum signal, the coil axis should be at right angles to the earth's field.

After removal of the polarizing field, the coil is connected to the input of a high-gain, narrow bandwidth audio amplifier and the precession frequency is measured. As the amplitude of the proton signal decays exponentially with a time constant of approximately 3 sec, the frequency of the signal is determined by measuring the time taken for 1000 proton

processional cycles to occur (Waters and Francis 1958).

In the deep-towed operation, the submarine vehicle contained the polarizing circuits and broadband audio amplifier and towed the bottle 100 ft behind the vehicle. Upon command from the surface, the sensing head (bottle) was polarized for 5 sec, then the polarizing field was removed and the audio signal sent up the towing cable. At the surface the signal was amplified by a narrow bandwidth ($Q \approx 300$) audio amplifier tuned to the proton frequency and counted by a Hewlett Packard 5233L counter (proton counter). This count was punched on tape, printed on a printer and recorded graphically.

3.1 GENERAL DESCRIPTION OF CIRCUITRY

In order to reduce the possibility of mutual interference between the side-looking sonar and the magnetometer it was decided to adopt a time-sharing form of multiplexing rather than to attempt complete simultaneity of operation. The system diagram is shown in Fig. 1. Although it was theoretically possible to operate the systems completely simultaneously, the short testing time available (three days) for trials of the magnetometer alone and in conjunction with the side-looking sonar suggested the time-sharing method. Future operations with the dual system operating simultaneously should be feasible provided sufficient development time is allowed for removal of undesirable system interactions.

3.2 DETAILED SYSTEM OPERATION

The repetition rate of the system was controlled by a preset counter which was set up so that its contacts closed for 400 ± 100 msec once every 20 sec (Fig. 2). This contact closure initiated the surface-polarizing timer

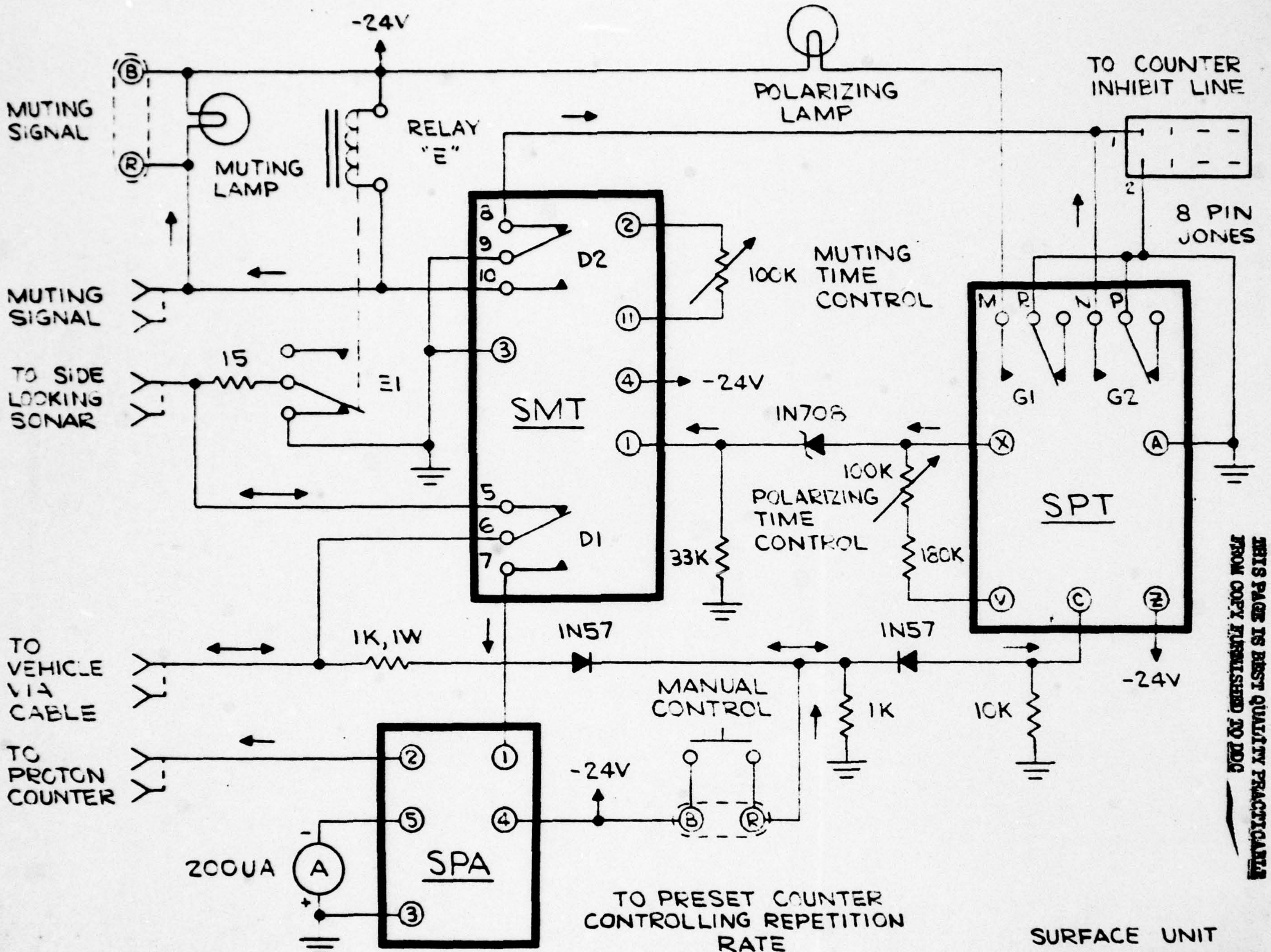


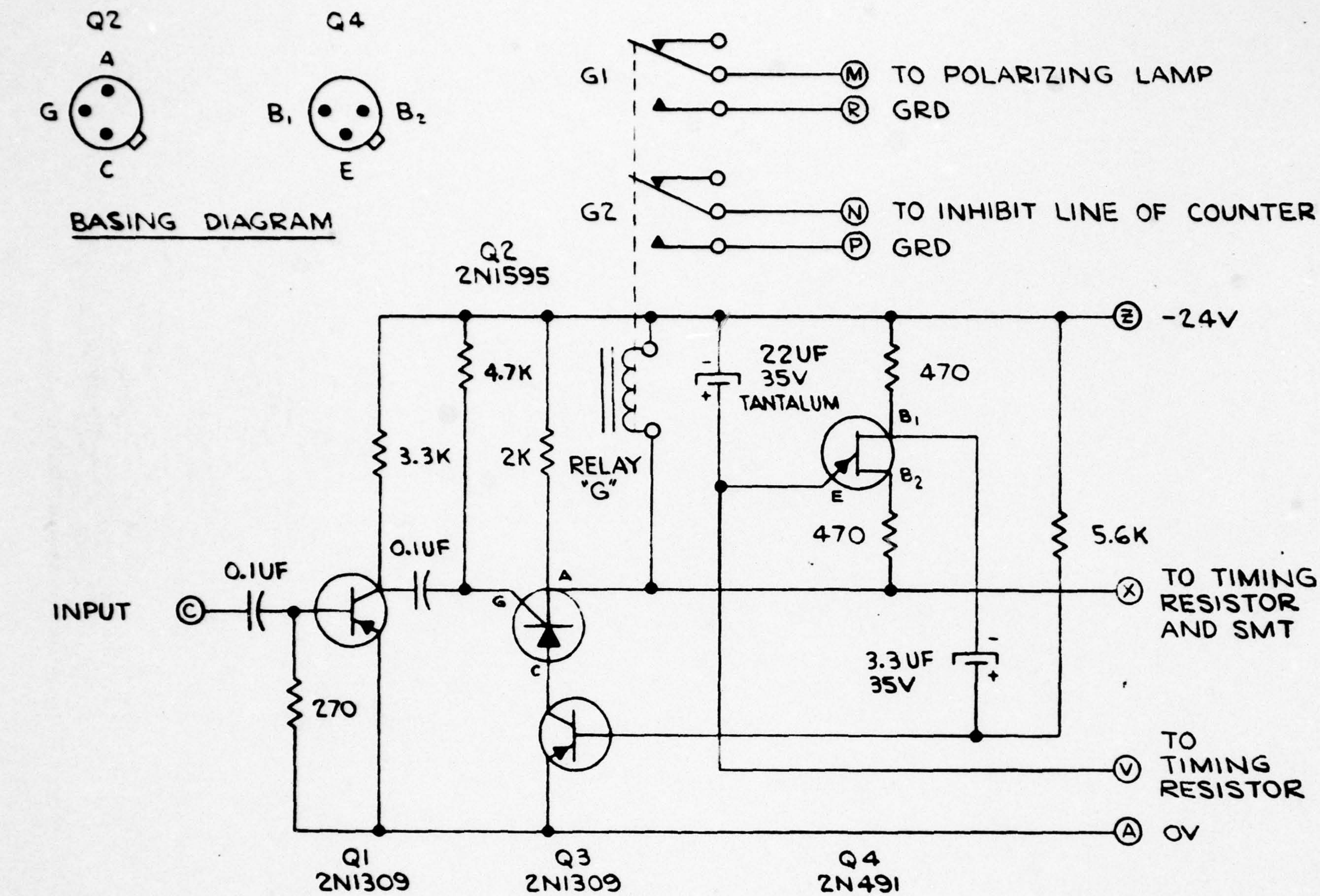
Fig. 2

SURFACE UNIT INTERCONNECTIONS

(SPT) (Fig. 3) and sent a -12-volt command pulse down the cable. In the deep-towed vehicle this pulse passed a low pass filter and operated the vehicle Schmitt trigger circuit (VST) (Fig. 4) which initiated the deep-towed vehicle polarizing timer (VPT) (Fig. 5) and hence the polarizing relays. Five seconds later the surface- and deep-polarizing timers completed their cycle and the polarizing relays opened. The output pulse from the polarizing timers operated the 1-sec muting timers (SMT [Fig. 6] and VMT [Fig. 7]) which energized the muting relays. As shown in Fig. 2, the muting relays disconnected the cable from the side-looking sonar equipment and connected the lower end of the cable to the output of the proton amplifier. The upper end of the cable was connected to the input of the tuned amplifier. In addition the inhibit line of the proton counter was released, allowing the counter to make a period average measurement over 1000 proton cycles. This measurement was then recorded on a punched tape, printed, and displayed graphically on a potentiometric recorder. One second after initiation the muting timers recycled and reconnected the co-axial cable to the side-looking sonar system at the surface and in the vehicle and the proton magnetometer system remained dormant until re-initiated by a pulse from the preset counter.

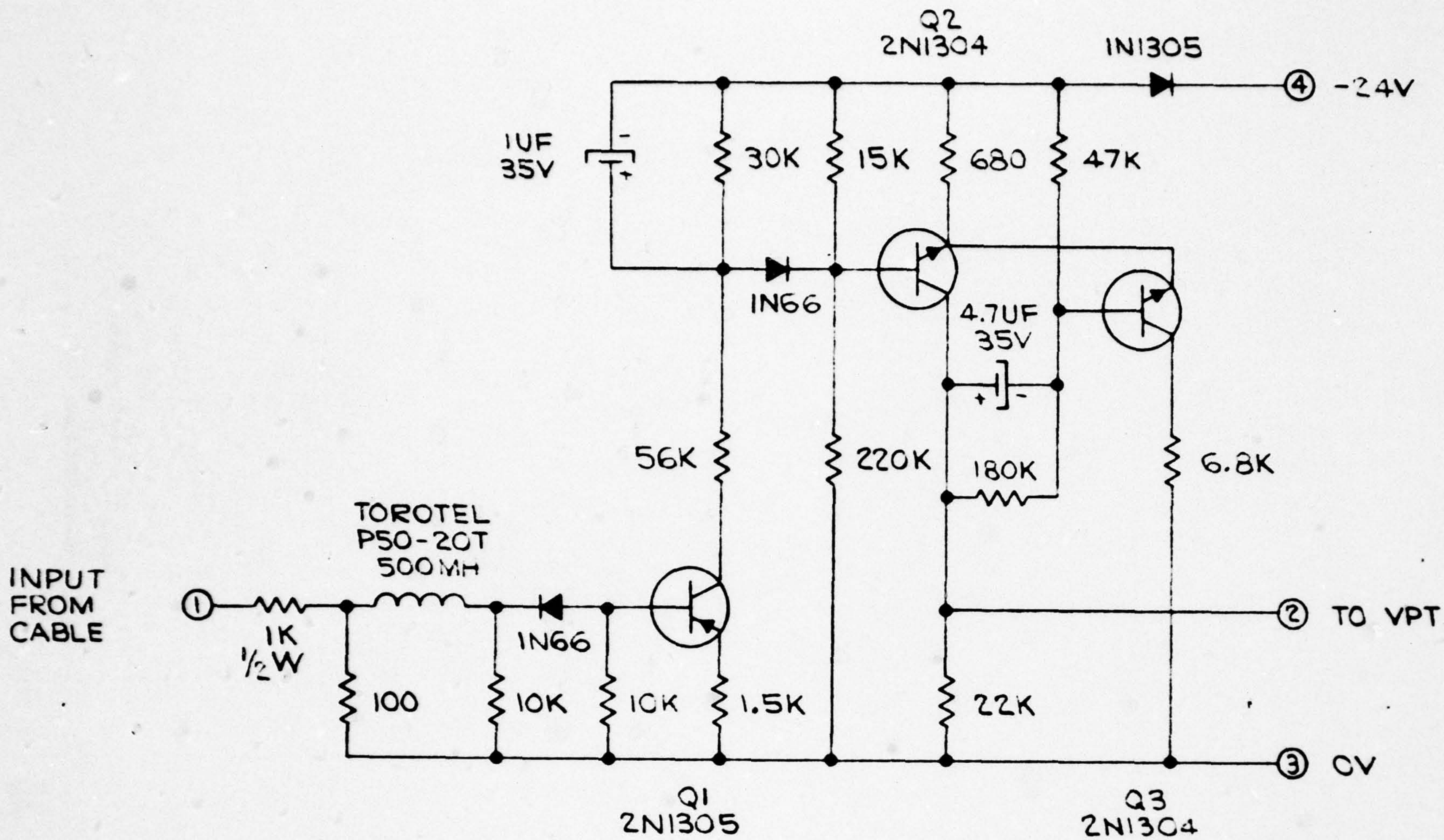
3.3 VEHICLE SCHMITT TRIGGER CIRCUIT (VST)

The 5-volt negative triggering pulse is filtered through the recognition circuits and causes VST-Q1 to bottom. If VST-Q1 remained bottomed sufficiently long to charge up the 1 μF capacitor, D2 conducted triggering the Schmitt trigger VST-Q2, VST-Q3. VST-Q2 remained conducting for 0.1 sec and the -ve pulse at pin 2 of VST was used to trigger the polarizing timer (VPT).



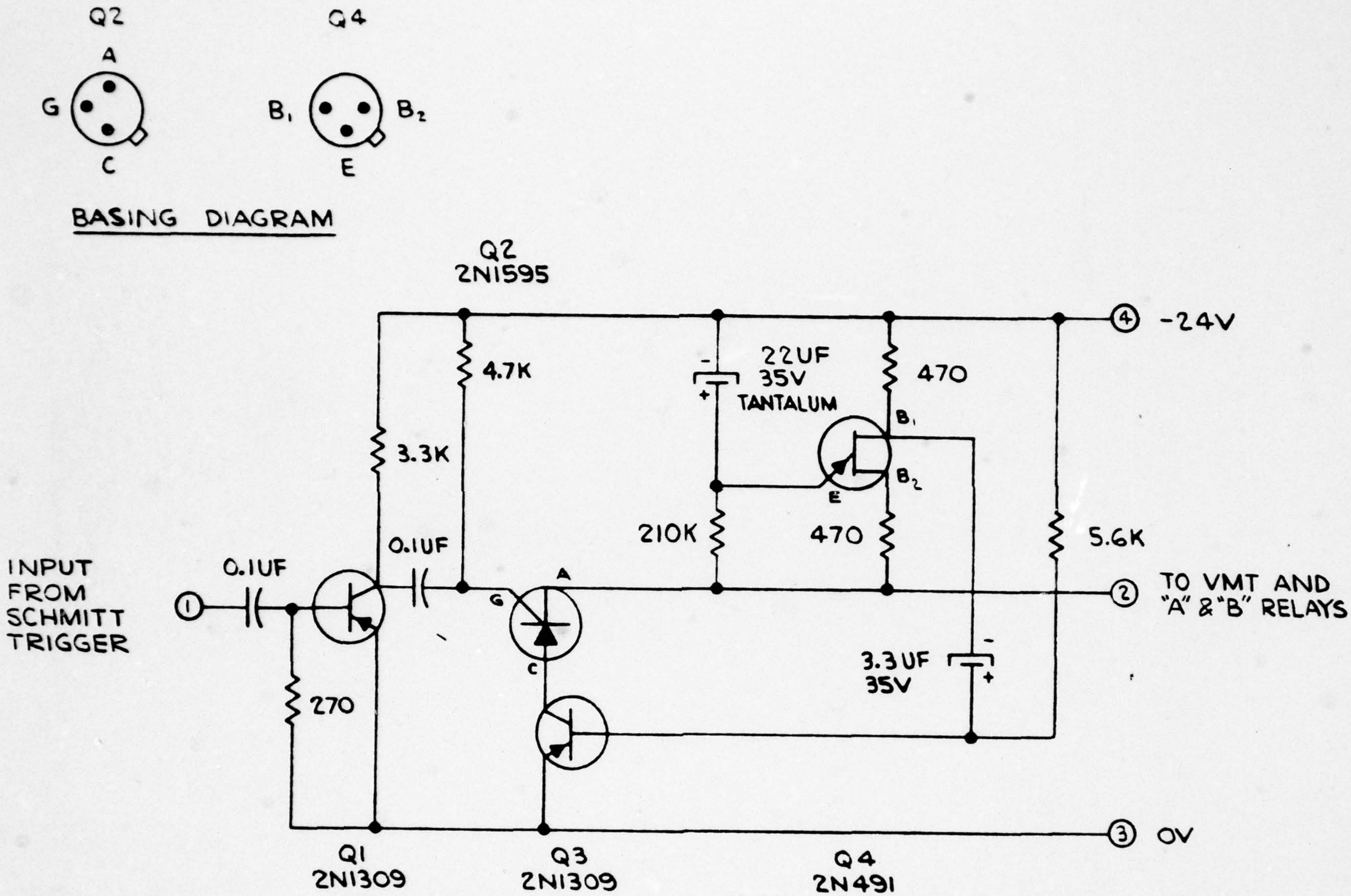
NOTES
1. ALL RESISTORS 1/4 W, ±10%.
2. RELAY "G": ELGIN ADVANCE, MV2C-600D-11 (26VDC).

Fig. 3 SPT
(SURFACE POLARIZING TIMER)



NOTE
1. ALL RESISTORS 1/4 W, ±10%
UNLESS OTHERWISE NOTED.

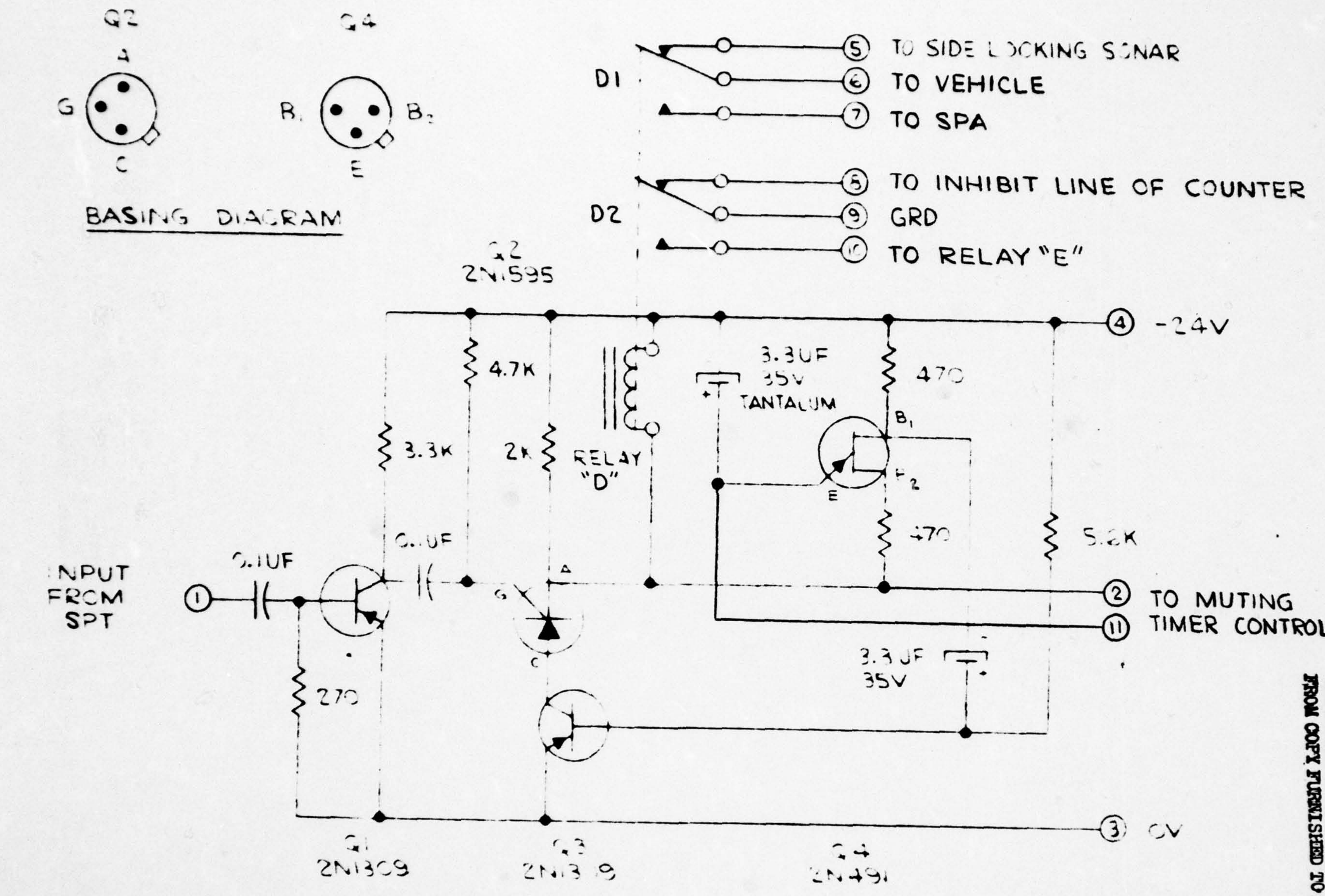
Fig. 4 VST
(VEHICLE SCHMITT TRIGGER)



NOTE

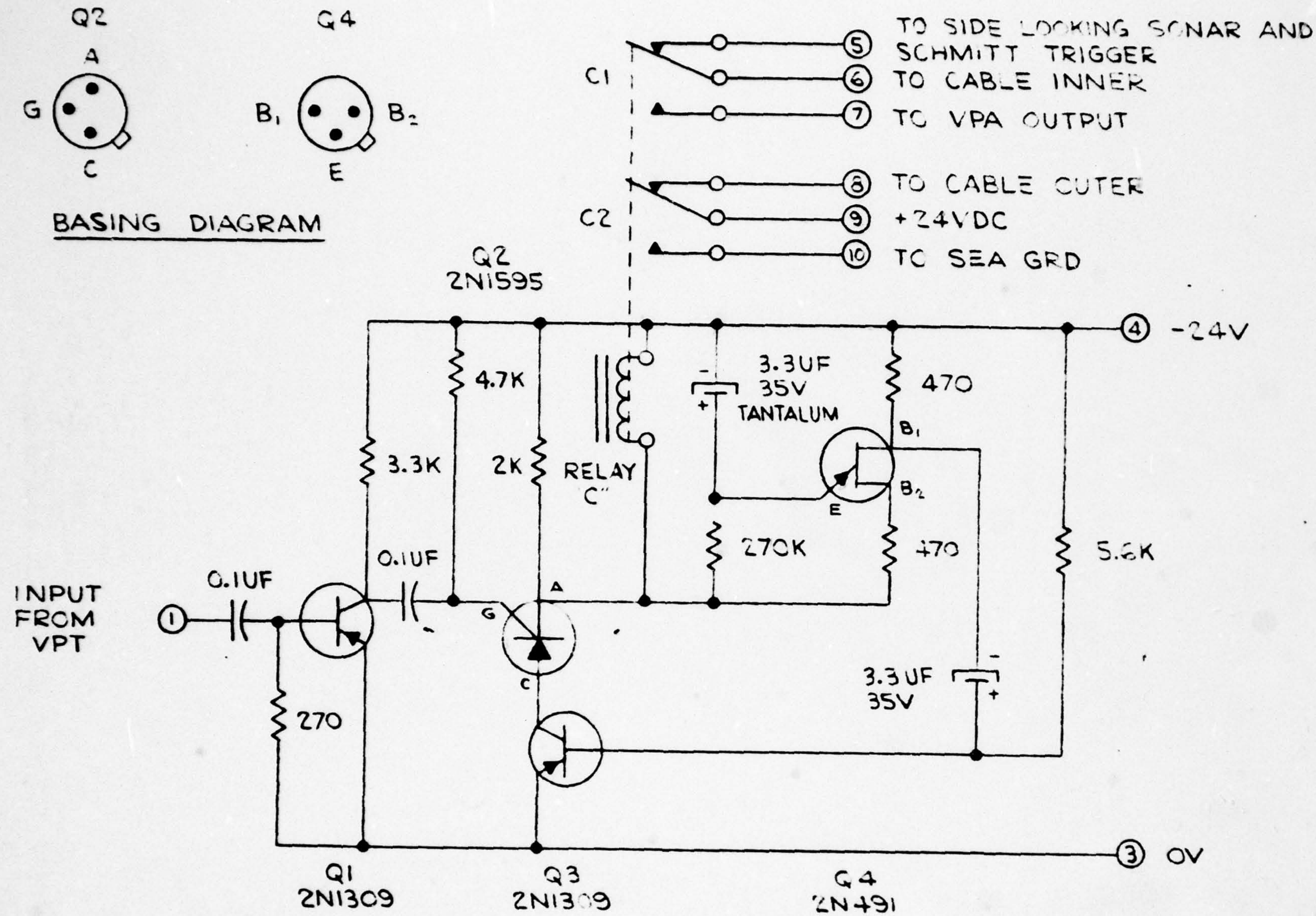
1. ALL RESISTORS 1/4 W, ±10%.

Fig. 5 VPT
(VEHICLE POLARIZING TIMER)



NOTES
1. ALL RESISTORS 1/4 W, ±10%.
2. RELAY "D": ELGIN ADVANCE, MV2C-600D-11 (26VDC).

Fig.6 SMT
(SURFACE MUTING TIMER)



NOTES
1. ALL RESISTORS 1/4 W, ±10%.
2. RELAY "C": ELGIN ADVANCE, MV2C-600D-11 (26VDC).

Fig. 7 VMT
(VEHICLE MUTING TIMER)

3.4 TIMER CIRCUITS (VST, VMT, VPT, AND SMT)

All timer circuits used are variations of a basic design in which a -ve pulse on Q1 causes it to bottom and thus switches on the silicon-controlled rectifier Q2 . Q3 is normally conducting and hence the relays are energized. In addition the timing circuit connected to the unijunction Q4 is energized. After a time controlled by the RC circuit connected to the unijunction emitter, the unijunction fires and a +ve pulse is applied to Q3 base which cuts it off. This cut-off extinguishes the SCR, Q2, and the circuit reverts to its quiescent state. The "muting timer" and "polarizing timer" controls on the surface equipment controlled the cycle length of the respective surface times and were used to ensure synchronization between surface and vehicle timers.

3.5 MODIFICATIONS TO COMMERCIAL EQUIPMENT

Tape Punch

In order to identify the readings, an event marker counter (HP5233L) was used. This counted minute pulses from the ship's clock, and the resulting count was punched as the first four characters in each word while the next six characters represented the proton count. A Dymec tape punch set DY 2545 was used and modified by disconnecting pin L of shift register 31 from pin N and connecting pin L to pin R instead.

A special mixer socket box (Fig. 8) was used to mix the output of the counters for the punch coupler.

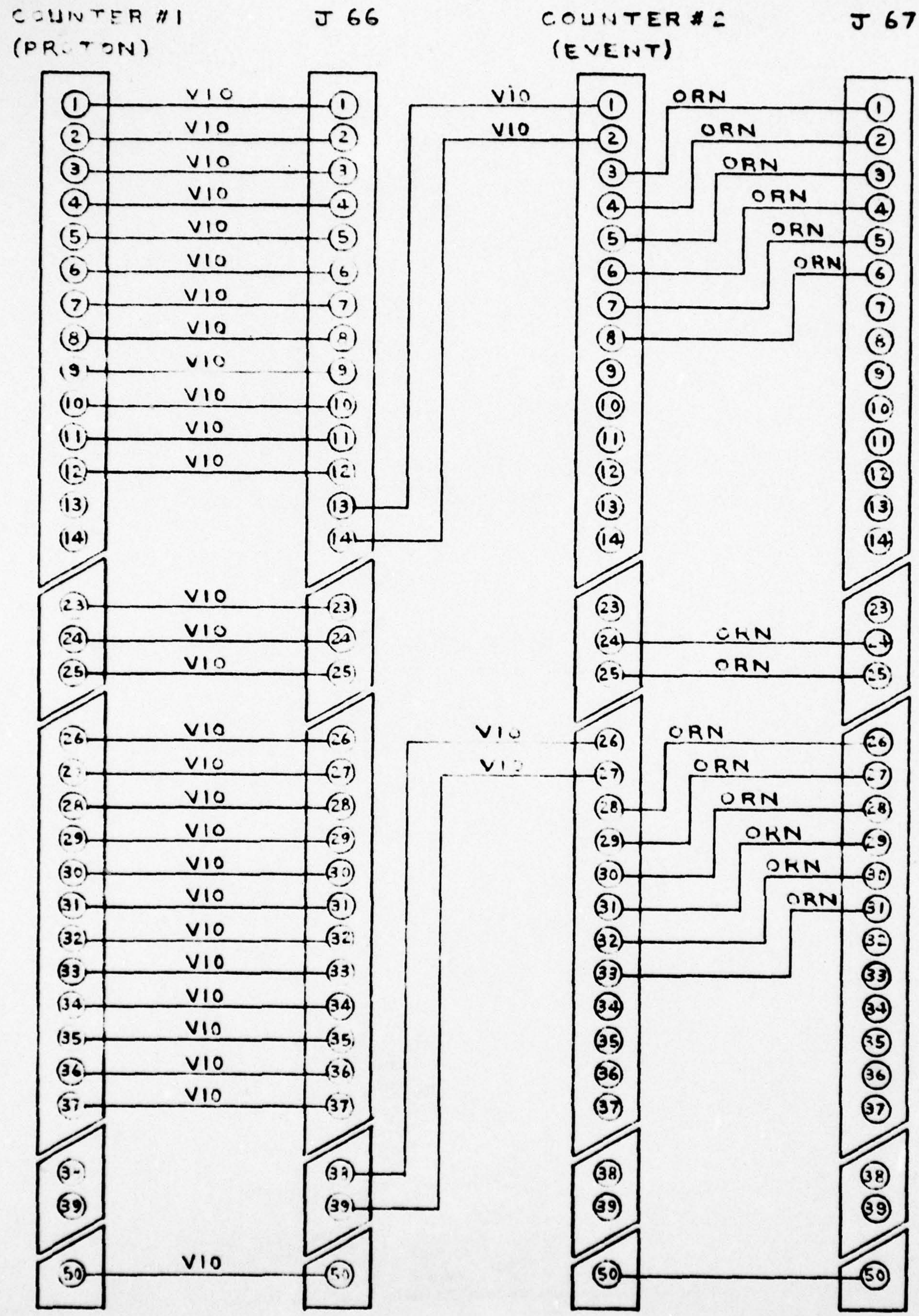


Fig. 8 MIXER BOX

Proton Counter Modification

The Hewlett Packard Model 5233L was modified:

1. To allow access to the inhibit line by connecting the "time base" socket to the inhibit line at pin B on socket A 17.
2. To prevent "ringing" in the tuned amplifier circuits from interfering in the proton frequency determination. This was achieved by a 520-cycle delay in the period-counting circuits so that accurate determination of the frequency did not begin until a quarter-second after release of the inhibit line. The reset lines on socket A 12 were changed from 1, 6, 10, and 13 to 2, 6, 9, and 12.
3. To allow a period measurement to be made over 2000 cycles, unit type 5212A-65C in socket A 13 was modified so that the pin was connected to the collector of Q1 instead of Q7. In addition the socket A 13 was rewired so that the "time base multiplier" lead was connected to A 13(4) instead of A 13(5).

3.6 TRANSDUCER CONSTRUCTION

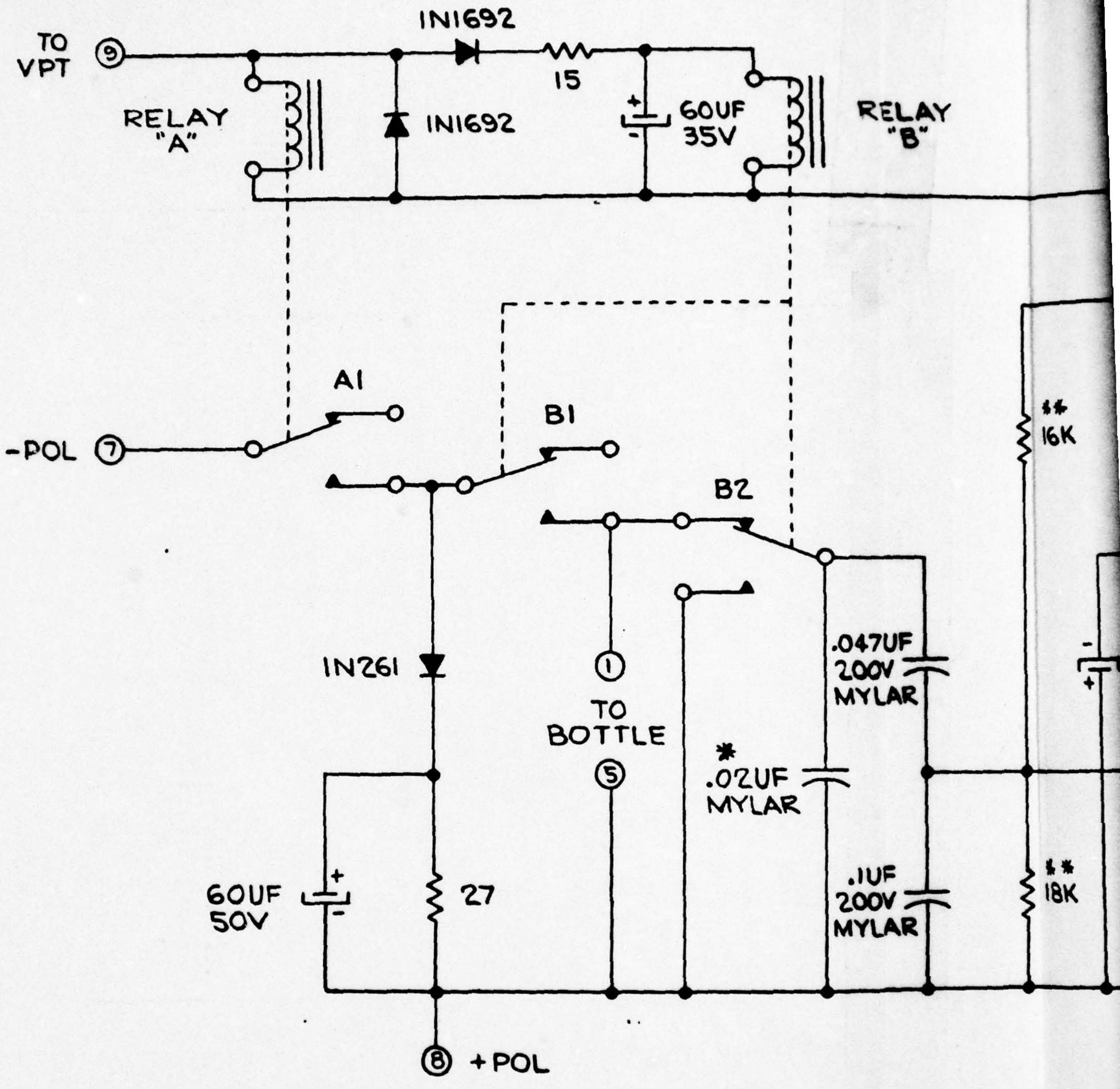
This transducer description does not refer to the transducers used on the Gibbs in April 1964 but to a subsequent design manufactured for the bathyscaph Trieste and tested to a pressure of 6000 lbs. One of these transducers has been used successfully at a depth of 2000 fathoms and no bottle failures have occurred to date.

The water sample consisted of a triply distilled water in a 250-cm^3 Nalgene container (2 $\frac{3}{8}$ - in. o.d.). To avoid air bubbles this container was filled and capped in boiling water and, after removal from the boiling water, the cap was sealed onto the body with RTV 102 silicon rubber (General Electric) to prevent leakage. The bottle should be potted within a week of sealing to avoid the formation of air bubbles.

The coil was layer wound from #20 gauge double enameled copper wire on a former; the coil was 2 $\frac{7}{16}$-in. i.d., 3$\frac{1}{4}$-in. o.d., and 4$\frac{1}{4}$ in. long. "Q dope" was used to preserve the integrity of the coil after removal from the former. The coil should have an inductance of 90 m H$\pm$ 10% and a Q greater than 35 at 1000 c/s . The coil was then potted (Appendix: Potting description) and attached to 100 ft of Simplex antimicrophonic cable. RG 57 U would most probably be satisfactory if the Simplex antimicrophonic cable is not available.

3.7 VEHICLE PROTON AMPLIFIER

The vehicle proton amplifier is shown in Fig. 9. During polarizing, relays A and B were energized (pin 9) by the vehicle polarizing timer VPT . The coil was connected to the polarizing supply by contacts A_1 and B_1 . At the end of the polarizing period, relay A released about 20 msec before relay B due to the 60μ-F capacitor across relay B . This allowed the diode-capacitor-resistor spark-quenching circuit to absorb the inductive energy of the coil, thus preventing damage to the A_1 relay contacts. (The physical processes involved in the removal of the polarizing field are discussed in Bullard, Mason and Mudie, 1964.) Relay B then released, removing the protective short circuit across the amplifier input



NOTES

1. RELAYS "A" & "B": ELGIN ADVANCE, MV2C-600D-11(26VDC).
2. T1: UTC, TYPE O-9.
3. CASES OF RELAYS & TRANSFORMER MUST BE CONNECTED TO COM GRD (PIN 3).
4. * : SELECTED TO TUNE COIL TO PROTON FREQUENCY.
5. ** : LOW NOISE.

1

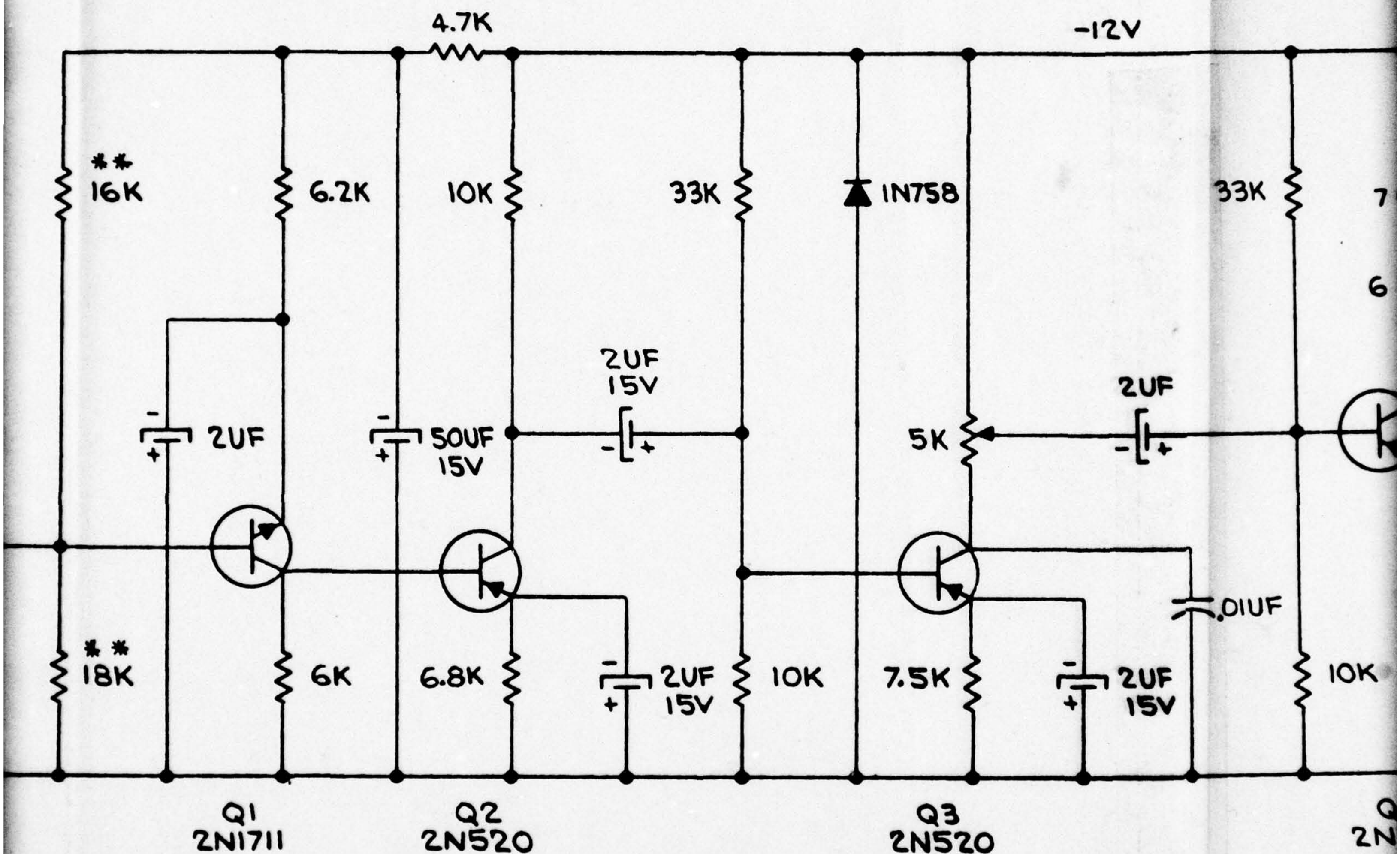


Fig. 9 VPA
(VEHICLE PROTON

2

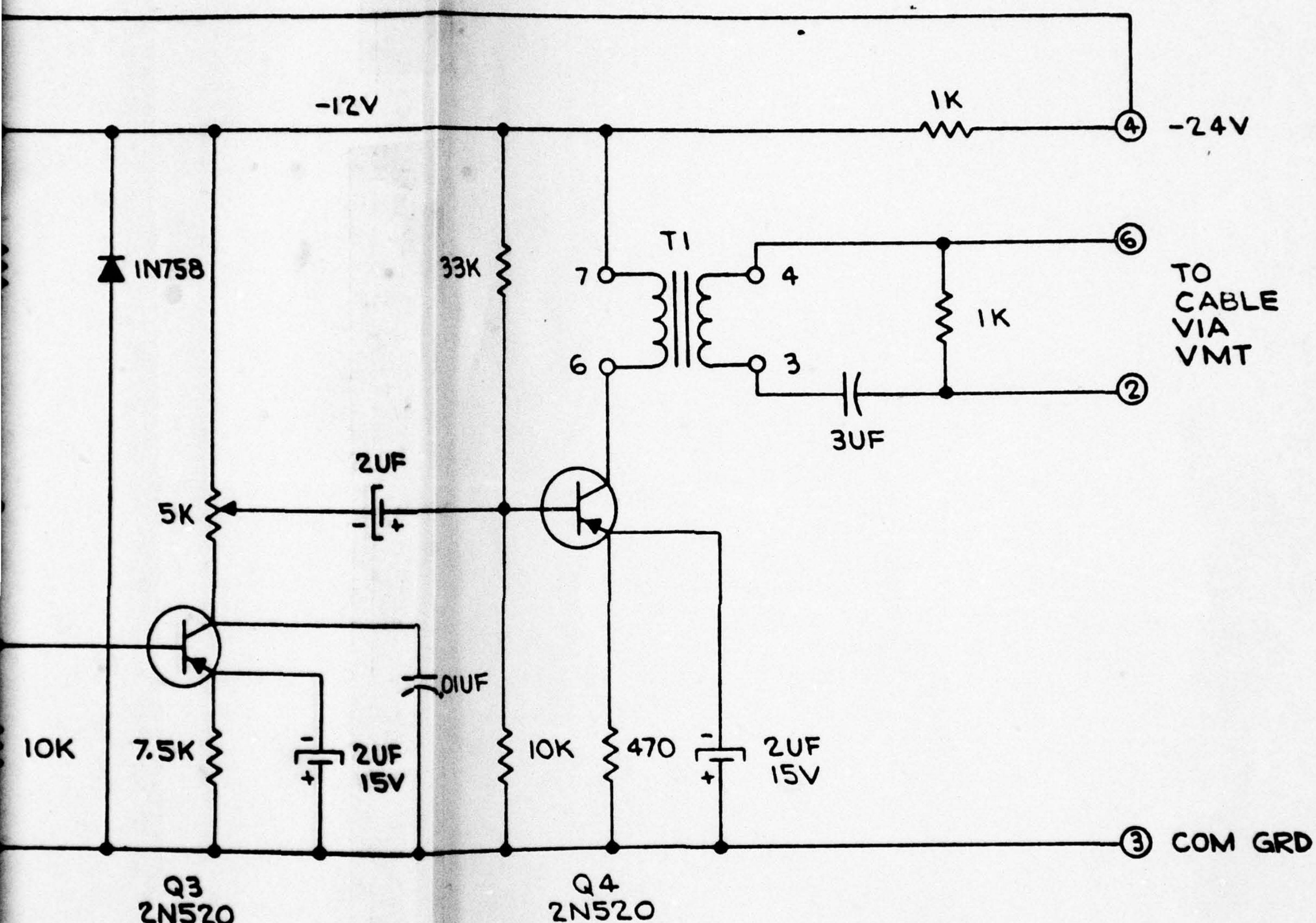


Fig. 9 VPA
(VEHICLE PROTON AMPLIFIER)

3

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and connecting the capacitive divider input of the amplifier to the bottle coil. This capacitive divider matched the high impedance of the coil to the relatively low input impedance of the amplifier. A tuning capacitor is selected for each area of operation and is chosen so that the coil is tuned to the proton precession frequency in the area. (Hydrographic Office Chart 1703 gives the total intensity, H , of the earth's magnetic field and the proton precession frequency may be calculated from $f = 4258 \times H$ cycles sec^{-1} where H is in oersteds.)

The gain of the four-stage amplifier is adjusted by the gain control so that the system gain is just less than that required to set the amplifier into oscillation. This tendency to oscillation is due to feedback between the output and input and is dependent on the particular wiring configuration used. In the 1964 operation there was typically a 30 mV p-p signal on the cable. The amplifier had a frequency response from 850 cps to 3.7 kc. The vehicle interconnections and battery pack are shown in Figs. 10 and 11.

3.8 SURFACE PROTON AMPLIFIER

The surface proton amplifier was a narrow-bandwidth, high-gain amplifier (Fig. 12). The center frequency could be set from 1000 cps to 3000 cps by adjusting the fine tuning controls FT1, FT2, and FT3. The tuning chart (Fig. 13) shows FT settings against 1000-period average measurement (proton count) and against magnetic field. This chart may be used for setting up the magnetometer. Once an area of survey has been established it is suggested that a more detailed chart be constructed which will aid in keeping the amplifier correctly tuned as the magnetic field changes.

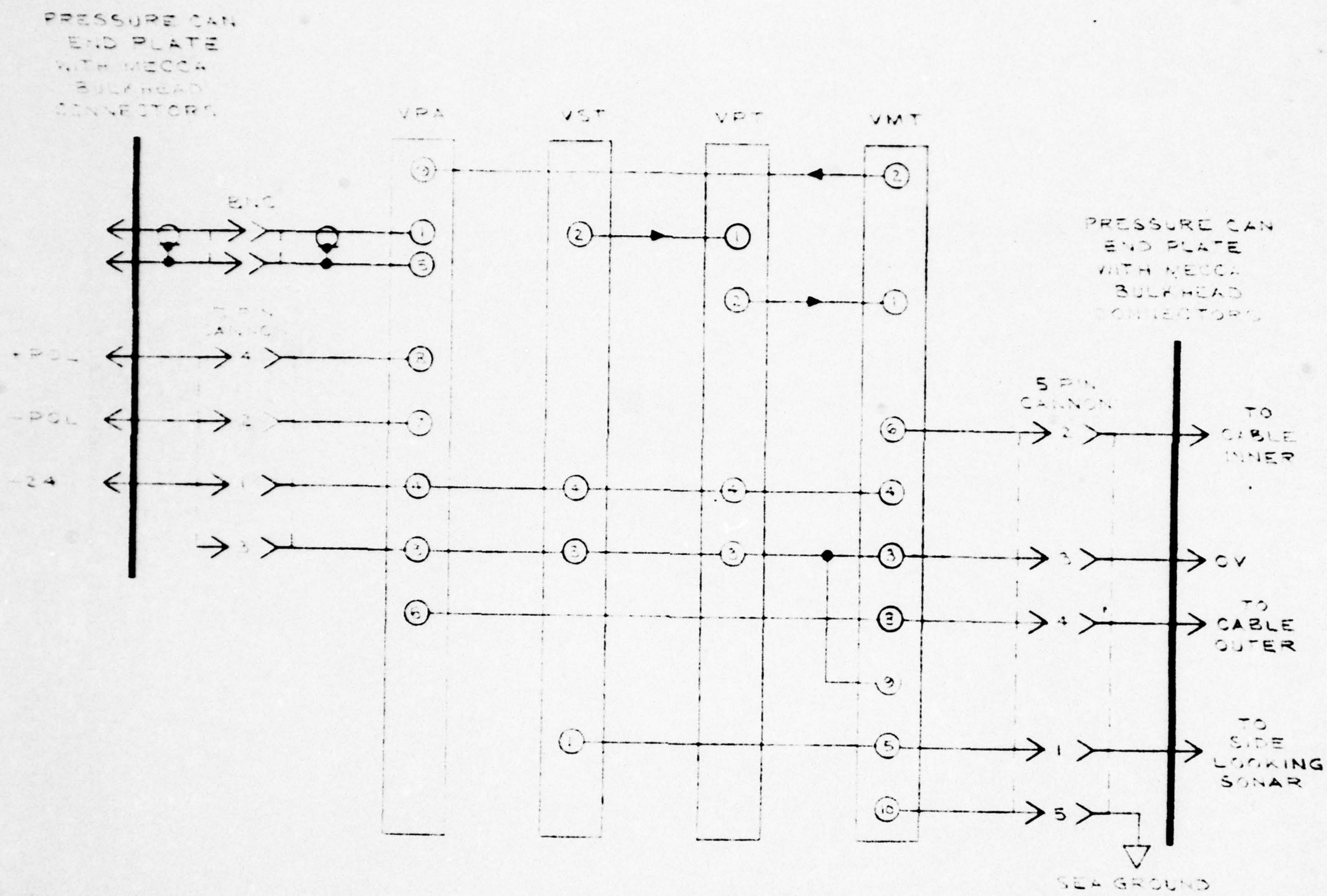
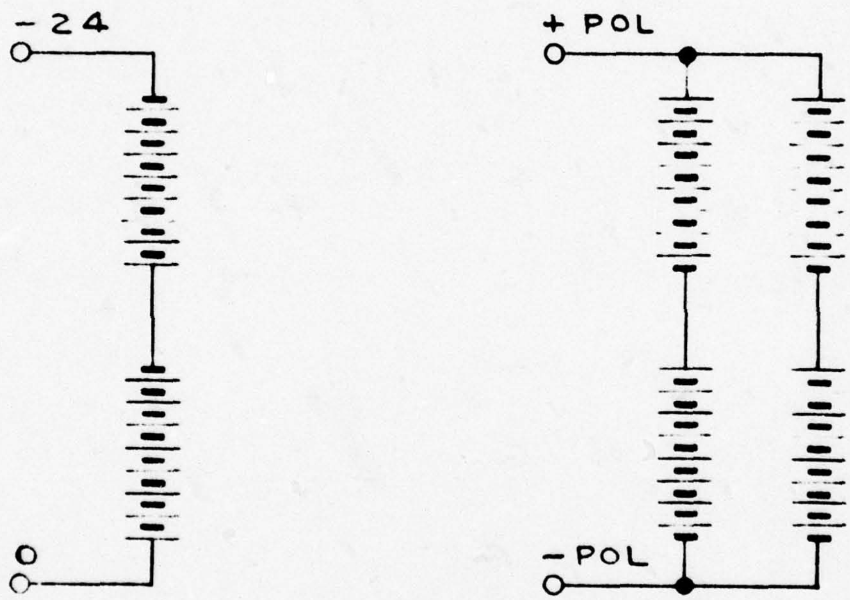
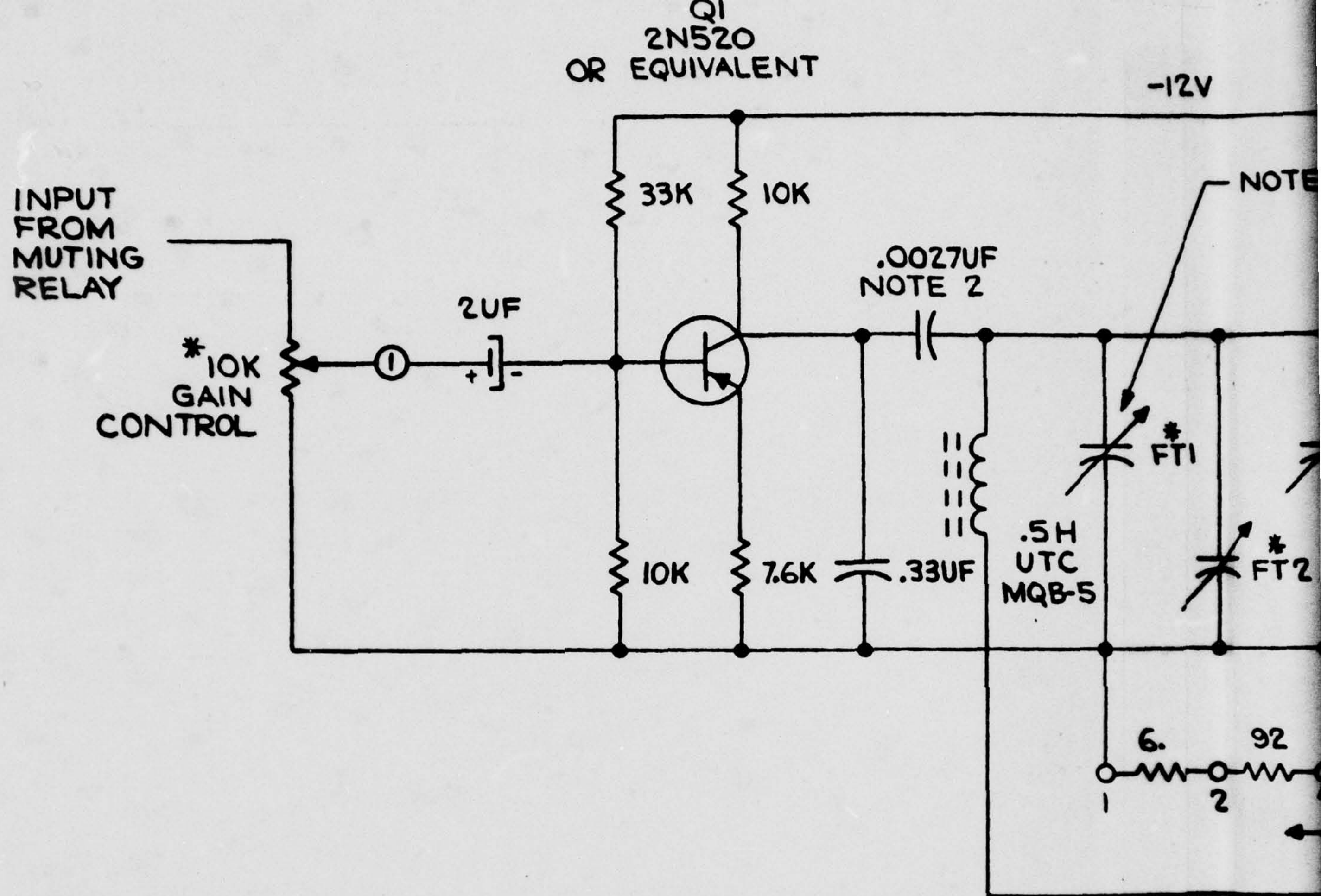


Fig.11. VEHICLE INTERCONNECTIONS



BATTERIES: BURGESS, TW2, 12V

Fig. 11 VEHICLE BATTERY PACK



NOTES
1. ALL RESISTORS 1/4 W, ±10%.
2. SILVER MICA OR GLASS, ±10%.
3. FT1 CONSISTS OF 9 CAPACITORS OF 4300UF EACH, FT2 CONSISTS OF 9 CAPACITORS OF 470UF EACH, FT3 CONSISTS OF 9 CAPACITORS OF 47UF EACH, MOUNTED ON PROGRESSIVELY MAKING SWITCHES.
4. *: DENOTES FRONT PANEL.

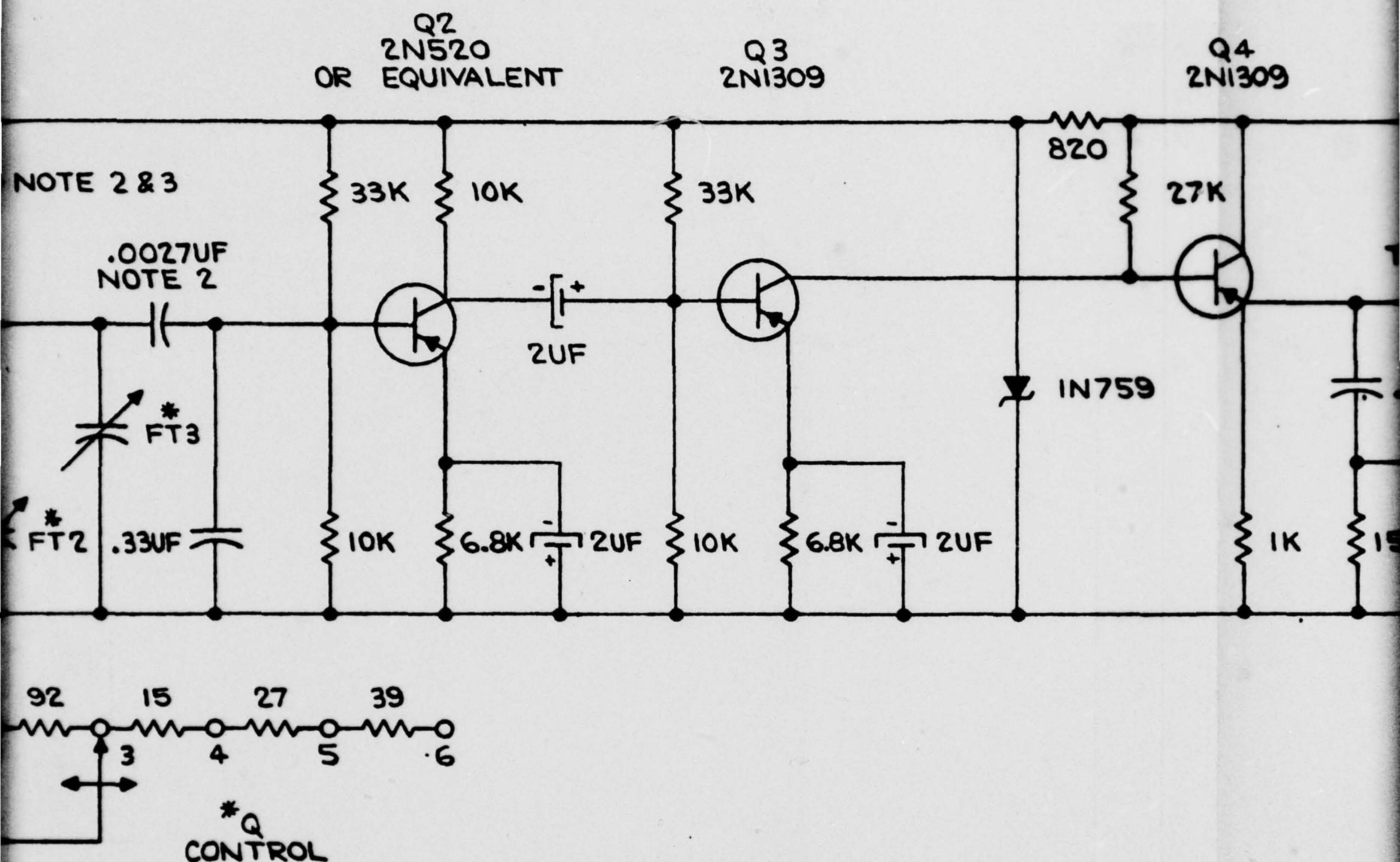


Fig. 12
(SURFACE PR

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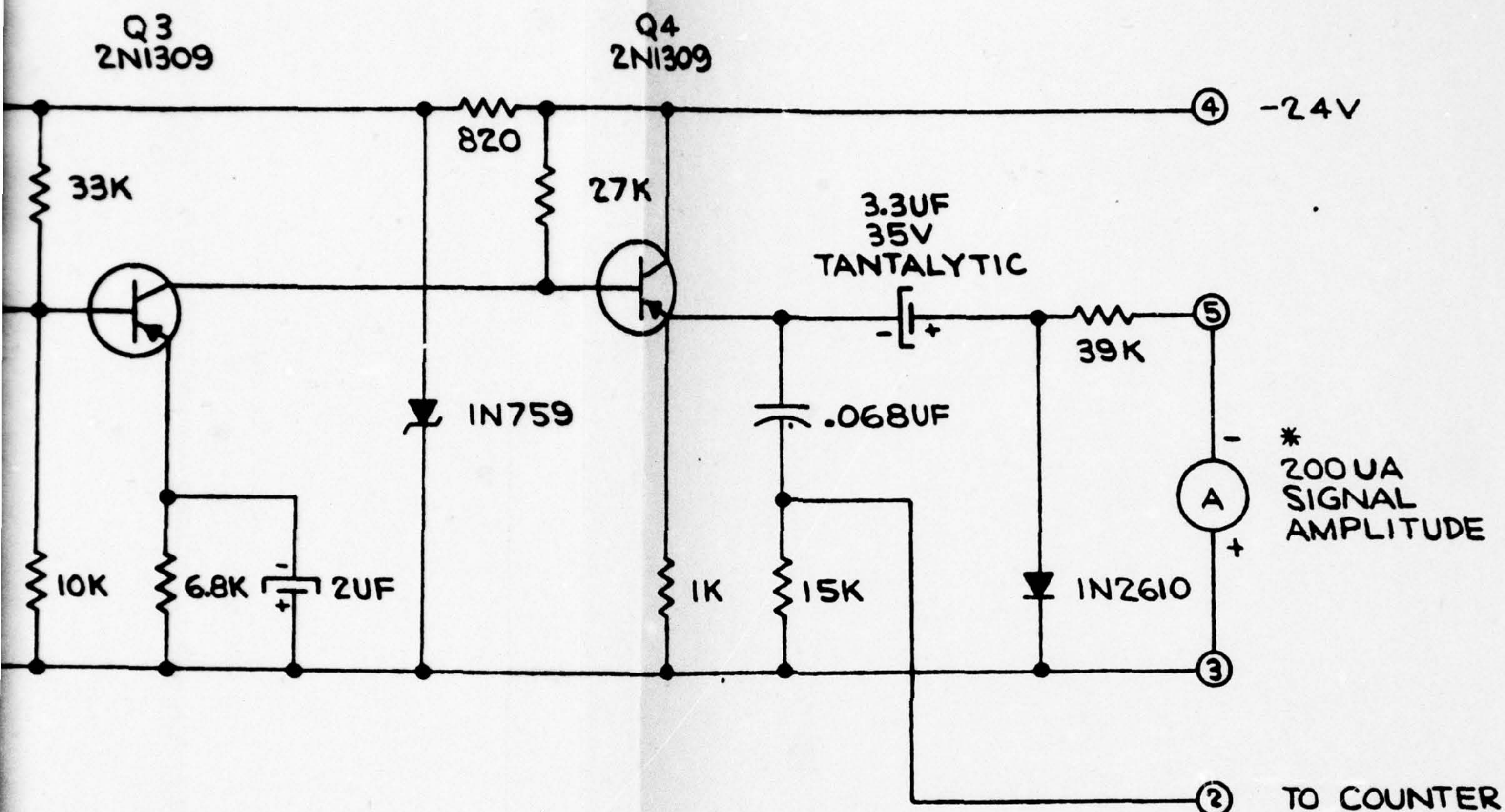

Fig. 12 SPA
(SURFACE PROTON AMPLIFIER)

3

EXAMPLE: FOR A FIELD OF 0.41942 OERSTED, THE PROTON COUNT IS 560000 AND FT 1=3, FT2=5 AND FT3=6 AS AT ※

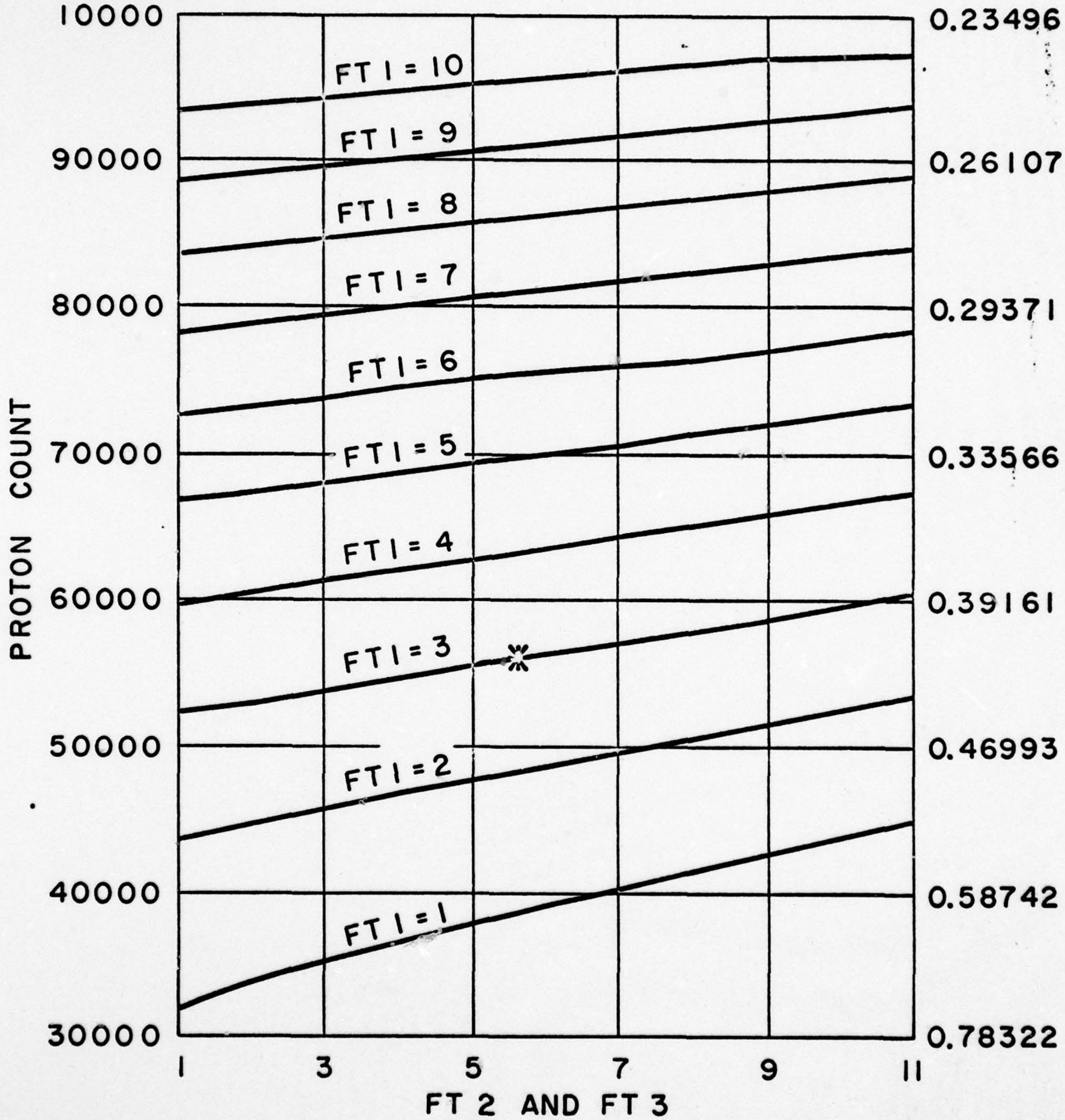

Fig. 13 TUNING CHART

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The Q of the filter may be changed by adjusting the "Q" control. The variation of bandwidth with "Q" control setting and with tuning is given in Fig. 14. Normally a Q setting of 4 should be adequate, but the narrow bandwidth should be used when necessary.

The gain of the amplifier was adjusted so that 10 volts peak-peak is fed to the counter (150 on signal amplitude meter).

3.9 CABLE

The cable initially used with the system was 28,000 ft of triple-armored co-axial cable (0.69-in. diam) with a capacitance of 0.1 mfd/1000 ft and a round-trip resistance of 3.3 Ω per 1000 ft. The cable had a yield strength of 45,000 lbs.

3.10 VEHICLE

The vehicle weighed 6800 lbs in water and consisted of a steel framework supporting a number of pressure cans which contained the electronic units and batteries. The magnetometer bottle was towed 75 ft behind the vehicle. The vehicle was towed for speeds up to 5 knots over periods of several hours in 8500 ft of water with 19,000 ft of cable out.[1] The vehicle was flown 200 ft ± 20 ft off the bottom. This required a high-speed winch capable of changing the cable length by up to 130 ft per min.

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[1] John Ess, Personal communication.

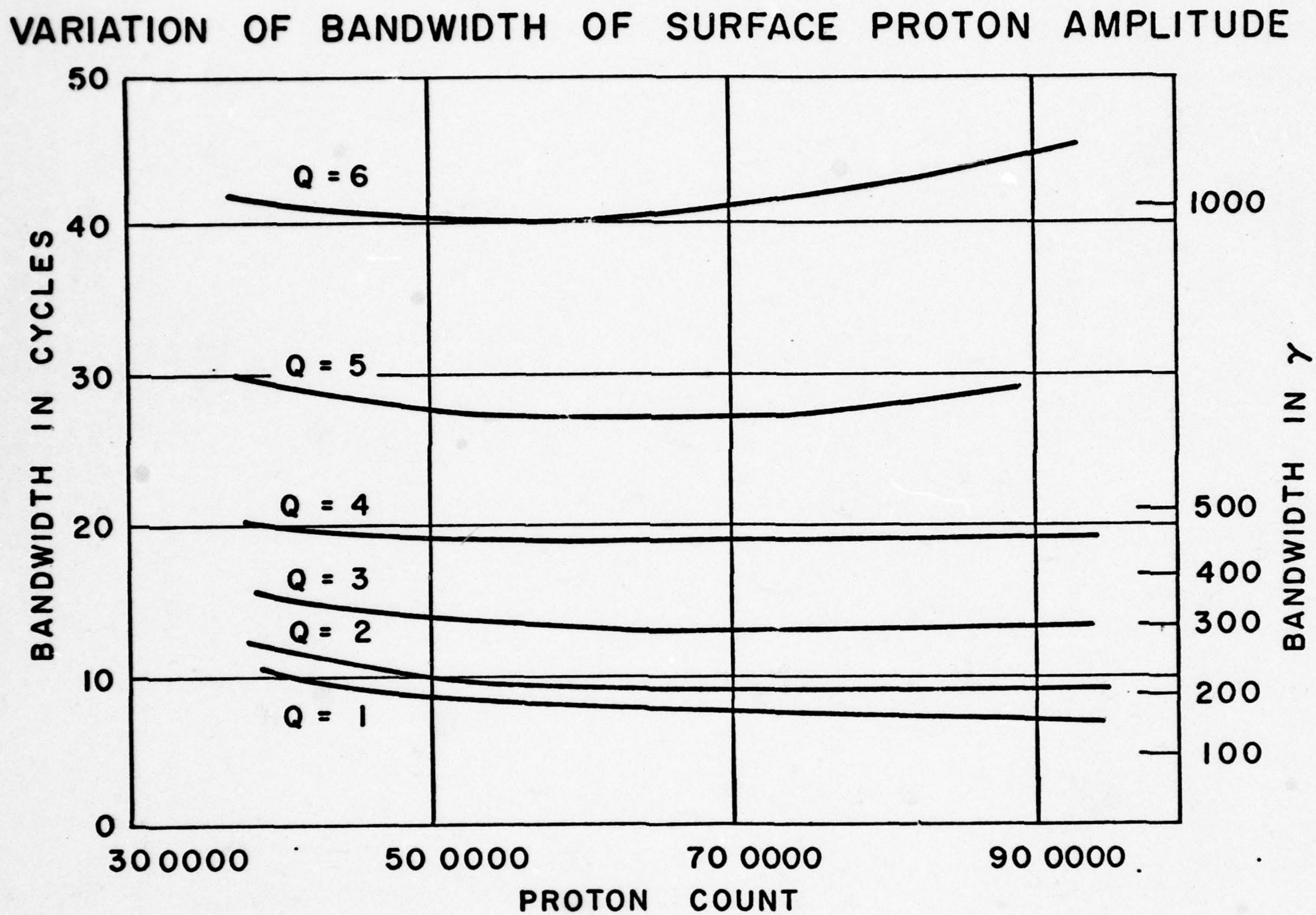
VARIATION OF BANDWIDTH OF SURFACE PROTON AMPLITUDE
BANDWIDTH IN CYCLES
50
40
30
20
10
0
Q = 6
Q = 5
Q = 4
Q = 3
Q = 2
Q = 1
1000
500
400
300
200
100
BANDWIDTH IN γ
30 0000
50 0000
70 0000
90 0000
PROTON COUNT

Fig. 14

The Hudson Laboratories deep-towed system has been discussed by Ess (1963).

4.0 DESCRIPTION OF DATA

4.1 The field at the bottle may be calculated from the formula

$$H = \frac{2\pi}{\gamma} \times 10^6 \times \frac{\text{cycles counted}}{\text{proton count}} \quad \text{oersted}$$

where $\gamma = 2 \cdot 67513 \times 10^4$ oersted $\sec^{-1}$.

"Cycles counted" is either 100, 1000, or 2000. Proton count is typically 42453, 424527, or 849055.

4.2 Both the tape and the printed output contain ten characters (with an end of word symbol on the tape) of which the first four are the elapsed time in minutes from an arbitrary zero (the zero time is noted in the magnetometer log) and the next six characters are the proton count. The number of cycles counted varied during the week but may be easily found by inspection of the data. A standard IBM eight-level code was used.

If	30,000	<	Proton count	<	50,000	then cycles counted			=	100
If	300,000	<	"	"	599,999	"	"	"	=	1000
If	600,000		"	"	999,999	"	"	"	=	2000

Some erroneous data and incomplete words appear on the tape due to malfunctions of the equipment. A coarse filter must be used in the input program to overcome these bugs. Note also that there are some cases in

which the proton count is 000 000. This will cause an overflow when using the proton count as a divisor unless care is taken on the input program to reject it.

Tape 1A was nonstandard and consisted of five characters of event markers while the last five characters were the last five characters of the proton count. This tape does not need processing as it represents the results of equipment tests over the Andrea Doria.

A program (Hudson Laboratories No. 303) has been written which will process a standard proton magnetometer tape. After reading in the time at which the event marker was reset, the computer prints the time (in hours and minutes) and magnetic field value in oersteds. The program was written by the Computing Section of Hudson Laboratories.

4.3 The chart recorder displays the last two figures of the proton count when "cycles counted" = 100, the last three when "cycles counted" = 1000 or 2000. Time marks were included on the record. A section of the record is shown in Fig. 15.

4.4 The proton signal was recorded on magnetic tape in order that the signal envelope may be studied for the presence of noise if the data appear to be spurious.

4.5 The effect of muting on the lateral echo sounder data is shown in Fig. 16.

5.1 RESULTS

Owing to the field repairs to a damaged bottle, the proton signal had a rapid decay (1 sec) and a considerably reduced signal amplitude resulting in a scatter which varied. At best the magnetometer achieved an rms

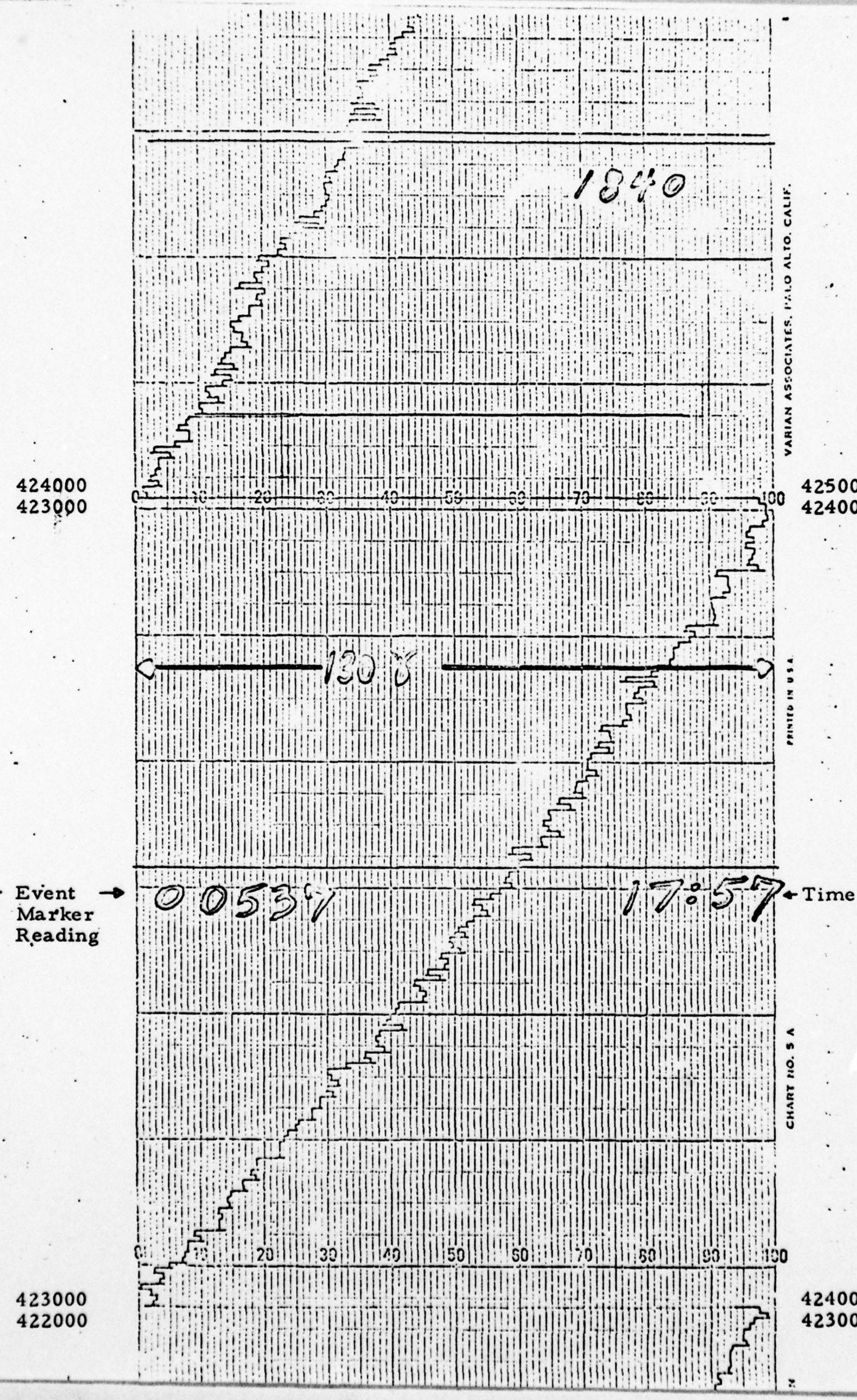

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FIG. 15 PROTON MAGNETOMETER RECORD

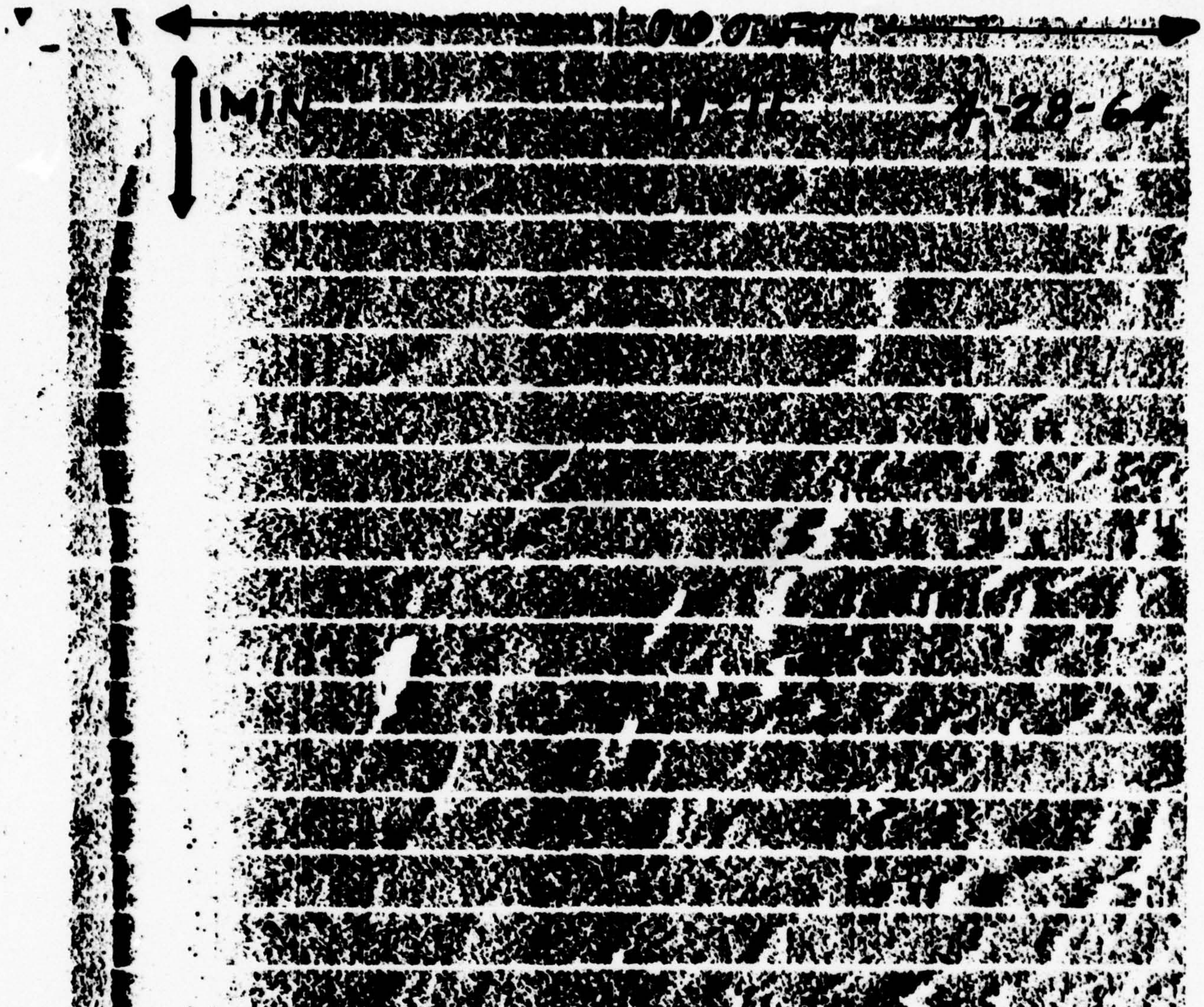

Fig. 16 SIDE-LOOKING SONAR RECORD SHOWING EFFECT OF MAGNETOMETER MUTING

reproducibility of 2γ. After the trip the bottle was tested and found to have acquired a 5γ heading error.

No significant magnetic anomalies were observed in the immediate Thresher area. A preliminary plot of the data indicated 50 to 100 γ differences at track crossovers. Further examination of the data will be carried out in an attempt to explain these differences which are most probably ascribable to the damaged bottle. At present no correction has been made for the diurnal variation of the magnetic field.

6.1 FUTURE DEVELOPMENT

The transducer described in Section 3.6 behaved as expected and worked satisfactorily. The signal amplitude fell off markedly when towed in a southerly direction due to the $\sin^2 \alpha$ factor mentioned in Section 2.1. In order to avoid this, a tri-axial bottle will be built which will consist of three coils with mutually perpendicular axes. The coils will be connected in series with each other. Each coil will have an inductance of c 30 mH and a resistance of 5Ω will be wound on formers c 3 in. long, 2 in. i.d.

6.2 ACKNOWLEDGEMENTS

This report represents the results of research sponsored by the Office of Naval Research Contracts Nonr-2216(05) and 266(84).

I also wish to acknowledge the help and cooperation shown by the staff of Hudson Laboratories, in particular that of Dr. C. S. Clay for the initiation of the idea of a combined magnetometer side-looking sonar search, of G. Lynch for multiplexing the systems, and of J. Ess for the deep-towed vehicle. H. Goldberg helped in the instrumentation; M. Benson of MPL designed the timer circuits, and J. H. Burritt of NEL, San Diego, potted the redesigned bottle and wrote the Appendix.

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APPENDIX

NEL Technique in Encapsulating Magnetometer Bottles

Step 1 - Mold Cleaning: Clean mold thoroughly with MEK (Methyl Ethyl Ketone) using Kimwipes disposable wipers (type 900S) (Kimberly Clark Corp., Neenah, Wisconsin). Let mold dry for 15 minutes.

Step 2 - Applying Release: Apply generously to all parts of mold release agent Hysol # 4368 (Hysol Corp., Olean, N. Y. or So. El Monte, Calif.). Let release dry for a half-hour; then lightly wipe with Kimwipes to remove the excess release agent. At this point be very careful not to touch any of the potting material, cable, or the tools which will be used later in molding, as there is a strong possibility that these items might become contaminated with release. Wash your hands often.

Step 3 - End-Sealing Cable: Trim outer jacket and shield back 18 in., exposing the two insulated center conductors (Fig. 1). Fold over the outer jacket of the cable about $\frac{1}{2}$ in. and remove all filler and shield flush to the cable jacket (Fig. 2). Rough up extremely thoroughly the entire exposed surface of the rolled down jacket with aloxite metal cloth 1-in.-wide # 50 grit (Carborundum Corp., Niagara Falls, New York). In addition, thoroughly rough up 12 in. of the insulation on the exposed center conductors. The emery cloth must be changed frequently to prevent contamination with cable waxes picked up by the emery paper. Wash roughed up areas thoroughly with MEK, dry off by blowing with 20-lb pressure of dry Nitrogen, and let stand for 15 min. Apply heavy coat of cable primer - PRC 1523 - (Products Research Co., 2919 Empire Ave., Burbank, Calif.). Use acid brushes -

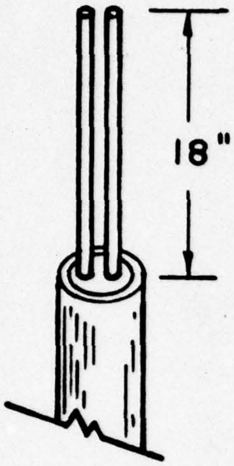


FIG. 1

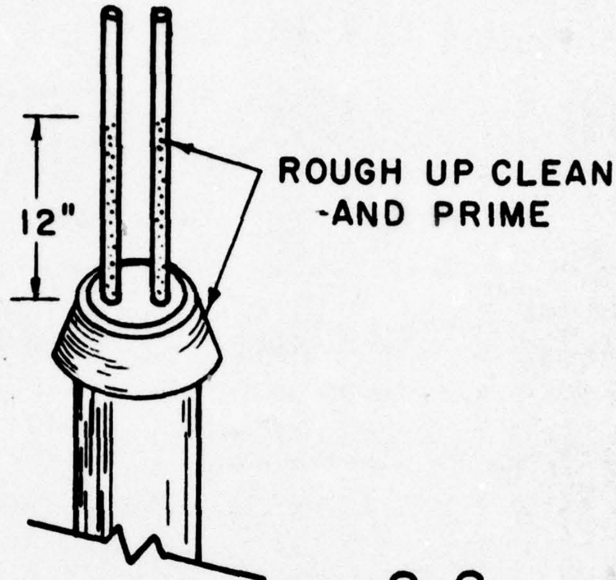


FIG. 2

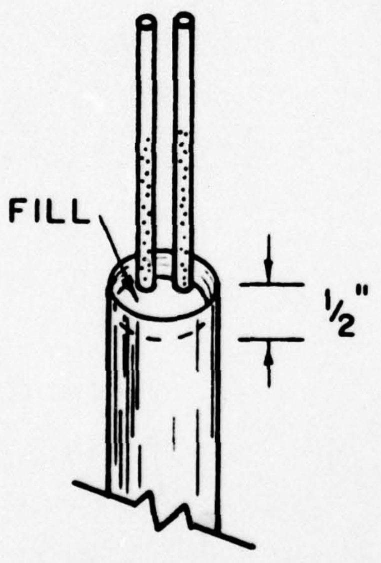


FIG. 3

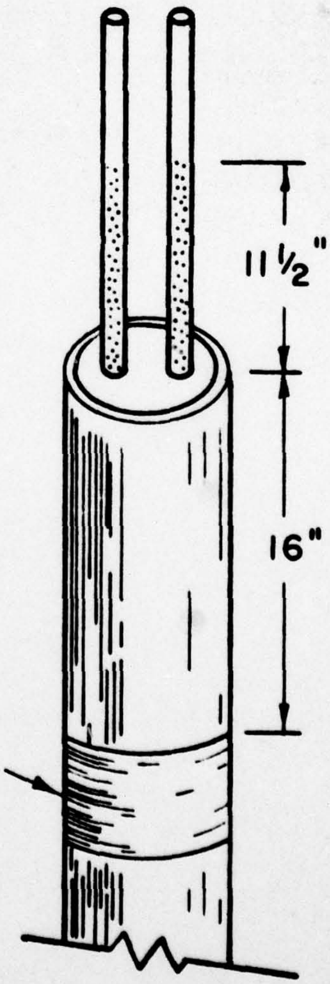


FIG. 4

change brushes after each dip in primer. Avoid contaminating the primer with dirty brushes. Blot dry with Kimwipes (changing wipes frequently) and let dry for $\frac{1}{2}$ hr. Do not touch any of primed area with fingers or contaminated tools. After drying, push up rolled down jacket into normal position as in Fig. 3; fill this cavity with EPOXOLITE R22; let cure approximately 3 hours or until tack free. This process is known as end sealing, and is done for two reasons: 1, to prevent air in the cable from entering the mold when potting; 2, to prevent water from entering encapsulated bottle if cable jacket becomes damaged.

Step 4 - Preparing Cable for Mold: Measure from jacket end of cable back along cable 16 in.; mark this with one wrap of $\frac{3}{4}$-in.-wide masking tape (Fig. 4); rough this area thoroughly with 50 grit emery using same method as in Step 3. Wash thoroughly with MEK (keeping contamination in mind), blow dry with Nitrogen; let stand 15 min., apply 1523 primer, blot dry, and let stand $\frac{1}{2}$ hr. At this point you may prepare a decontamination shield to be used later in installing cable in the mold. This is to prevent contamination of the cable when it comes in contact with the mold while assembling.

Step 5 - Preparing Decontamination Shield: Obtain a $\frac{1}{2}$-in.-diam wood dowel about 36 in. long. Use a no-lint type paper (brown wrapping has been found to work well for this). Wrap one layer of brown paper around dowel and tape about every inch (see Fig. 5). Remove paper from dowel. You will now have a paper tube 30 in. long. Slip paper tube over end of cable and slide it down to the masking tape mark (Fig. 6); be careful not to touch primed cable area with hands. Tape paper tube to conductors at cable end. Do not tape at other end.

FIG. 5

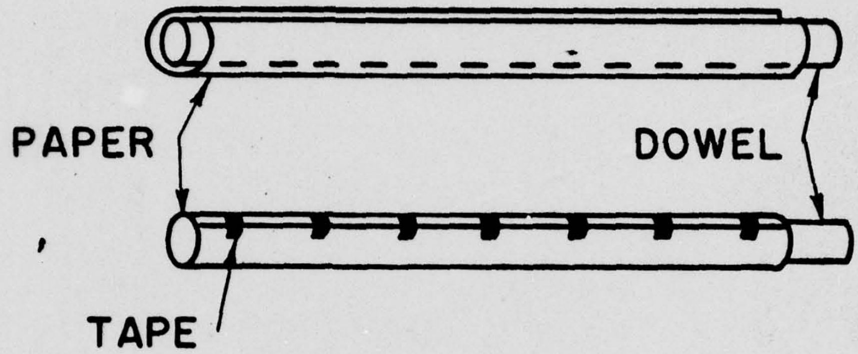
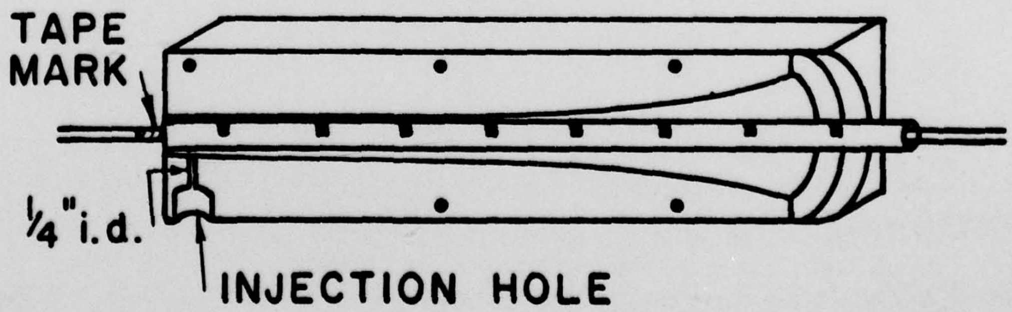


FIG. 6

FIG. 7



Step 6 - Insert cable into one half of mold up to masking tape mark; install second half of mold and bolt together leaving paper tube in mold (Fig. 7). Stand mold on end, cable end down with injection hole toward you. Obtain a suitable stand with weighted base. This stand must have adjustable fingers or bracket. Take the loose ends of the conductors and tie them securely to the fingers (Fig. 8a and 8b); pull the cable as tight as possible and align cable in center of mold. When assured that the cable is centered and not touching any part of the mold, you may remove the paper tube as carefully as possible (use scissors to cut tape). Don't drop any foreign material in the mold. Now insert the two $1\frac{1}{2}$ -in. - wide extensions into top of mold and tap down until seated at bottom. These extensions serve the purpose of providing a recess between material and mold for the 6-in. extensions used in the second pour. If 6-in. extensions were used first it would create working difficulty in the first pour. See Fig. 9 and illustration (Fig. 9a). You are now ready for first pour.

Step 7 - <u>First Pour:</u> We have found that injection of the first operation has been more successful than actually pouring the material into the mold, owing to the "folding"-in of air, which causes air bubbles. For the injection of the material we use Semco plastic cartridges, plungers and nozzles, and Semco sealant guns (Semco Sales and Service, Inc., 1313 W. Florence Avenue, Inglewood, Calif., Phone Oregon 8-5781). In this operation we used the 12-oz cartridges with plungers, No. 440 nozzle, 12-oz retainer and gun. We used PRC-1527 amber polyurethane for this project. Mix material as the factory recommends. We mixed 630 grams at one time in a # $2\frac{1}{2}$ metal can (General Can Co., 2900 E. 11th St., Los Angeles 23, Calif.). At this point construct a flue from four of the cans (Fig. 10). Cut

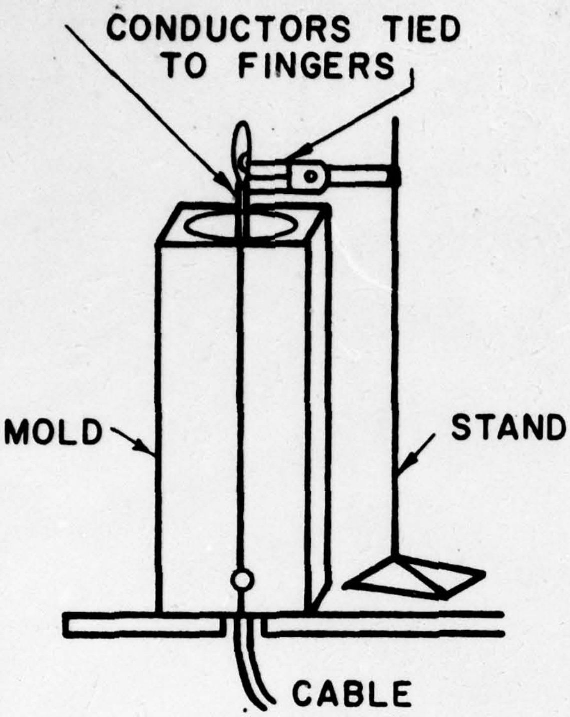


FIG. 8a

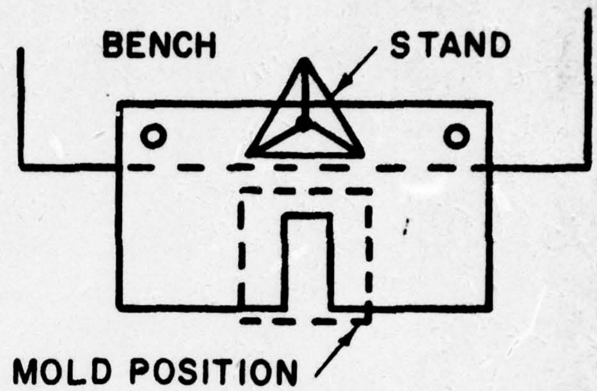


FIG. 8b

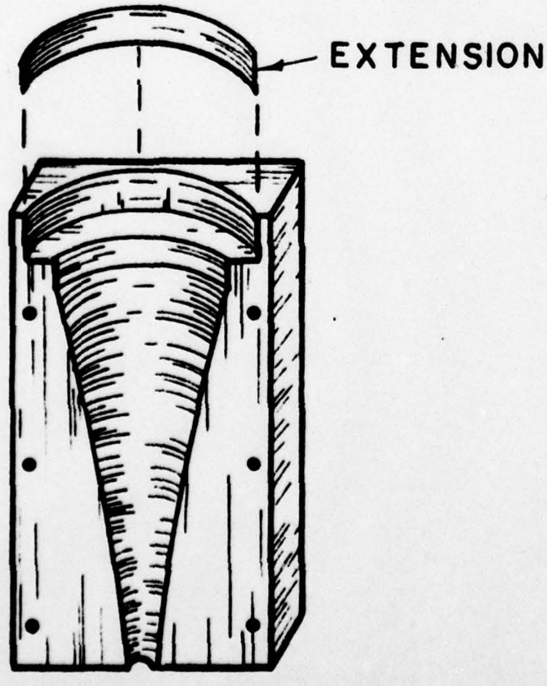


FIG. 9

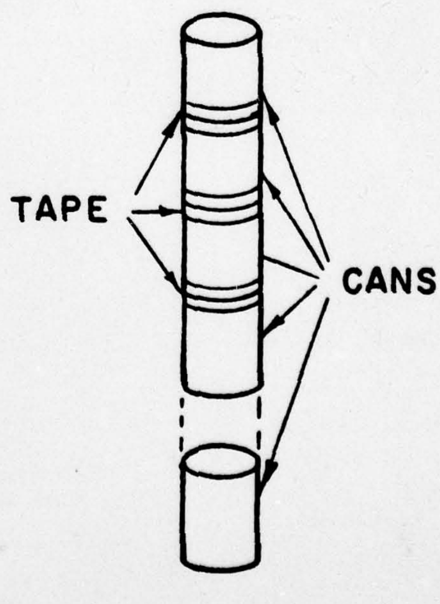


FIG. 10

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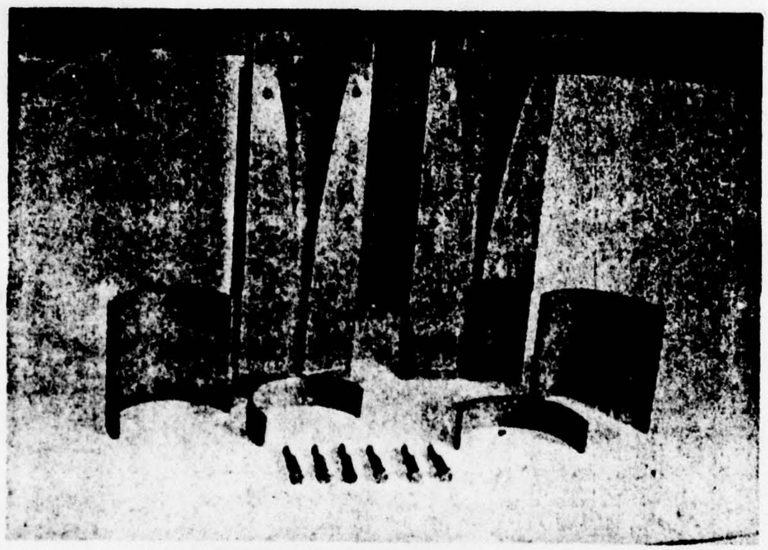


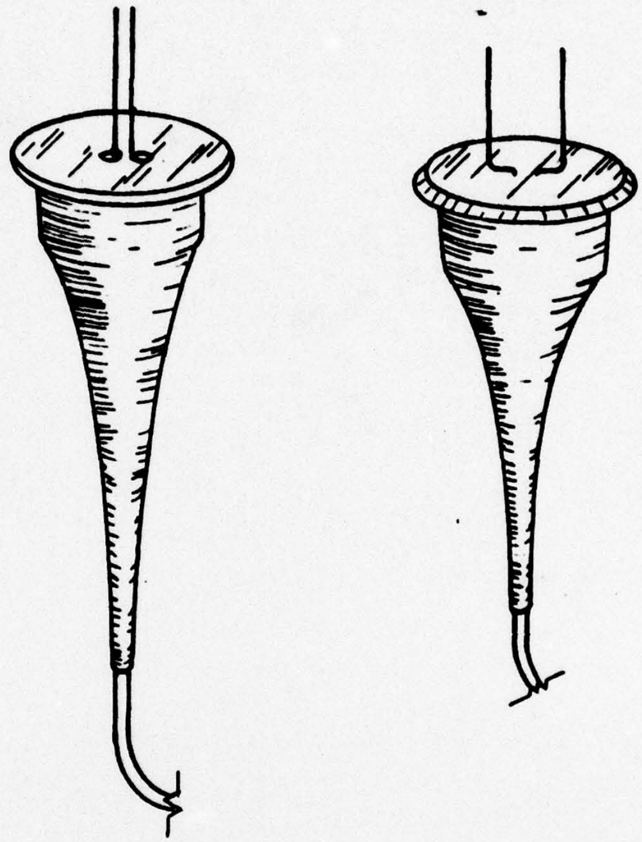
Fig. 9a MOLD

the bottoms out of the four cans; stack them on top of each other and hold them together at their seams with 2-in. masking tape. When this step is completed, set the flue on top of the nearly full can of material and tape flue to material can. Now set material, with flue attached, into a sufficiently tall vacuum tank. Your tank must have a plastic window so you can observe the action of the material. Start the pump, and when vacuum reaches about 28 or 29 in., the material will start to rise in the flue. Let it climb to near the top of the flue. If it appears that it may flow over the top, release vacuum slightly and let it drop down about 4 or 5 in. in flue; close air vent and repeat operation if necessary. When material has evacuated, it will fall back into material can. It will appear to be boiling; leave it in vacuum tank for 15 min. or until boiling appears to have stopped. Remove from tank. Remove flue from material can; install nozzle in 12-oz cartridge; seal nozzle end with masking tape. Bend material can so that there is a pouring lip, and pour material down the side to avoid "folding"-in air, until tube is about half full. Place the two tubes in a stand and put them back into the vacuum tank. Repeat steps laid out in above operation. When all air appears to be evacuated from tubes remove them from tank, insert plungers, insert tubes in retainer, install retainer onto gun, remove tape from nozzle, and pump trigger on gun until small amount of material comes out nozzle end. This removes all air (if any) from nozzle. Insert nozzle into injection hole and pump <u>very slowly</u> until about 3 in. of material is in bottom of mold. At this point stop pumping; keep gun in injection hole; wait for about 3 or 4 min.; use heat gun, with the switch in heat position (Model No. H6-751. 20 AMP, heat gun 110. 120 VAC-DC, Master Appliance Corp., Racine, Wis.). Aim heat gun down into mold, and let run for about 30 sec. This breaks up small surface bubbles that tend to float on the top. Repeat pumping process until

you have another 3 in. in mold; repeat heat gun application; repeat entire process until material is $\frac{1}{4}$ in. to $\frac{3}{8}$ in. above first level of mold. Remove gun and quickly plug up the injection hole with $\frac{1}{8}$-in. pipe plug. For the first pour it will take 1260 grams of material; in other words, two batches of material will have to be mixed, using same procedure as aforementioned. When material is at proper height in mold, let stand for about 15 or 20 min. or until all visible air bubbles are on the surface. Use heat gun to break them up, and repeat this process as necessary - watch material at this point. When it starts to gel, no further work can be done. Let stand overnight - do not apply heat.

Step 8 - Next morning open mold carefully, remove molded product, lay aside for time being, clean mold as in Step 1, clean and release 6-in. extensions. Wash your hands to remove all traces of release agents. Before placing molded product back into mold there are two steps to perform: 1, Trim edge of the flared portion of products as shown in Fig. 11, using razor blade or exacto knife. This is done to add a larger bonding area at seam of second pour and also will add to the appearance of finished product by not showing a bonding seam between the two pours. 2, Two small slots or trenches must be cut at right angles to the two exposed conductors as shown in Fig. 11. These slots should not be any longer than the diameter of the coil to be potted, nor deeper than the diameter of the conductors. The reason for this is to allow a flat surface for the coil to rest on and to allow the conductors of the cable to lie along the outside of the coil for easy termination to the leads of the coil. After this phase is completed, clean the top surface and the newly trimmed edge thoroughly with MEK and Kimwipes; also clean the exposed cable conductors. The material will become somewhat

FIG. 11



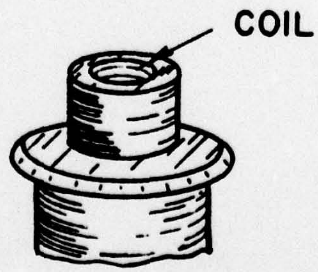


FIG. 12

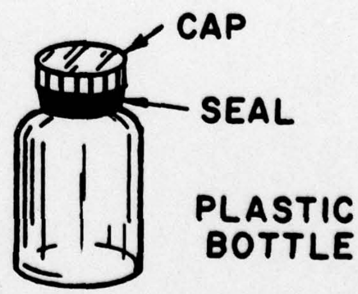


FIG. 13

tacky when cleaning. This is normal for uncured material. Carefully place products back into mold, replace screws, and tighten up. Do not touch cleaned area.

Step 9 - Installation of Coil: Before installing 6-in. extensions, the coil must be connected to the cable conductors. Lightly brush clean coil with bottle removed. Using a non-lint-type napkin, pick up coil and place in center of first half of mold and between the cable conductors (Fig. 12). Terminate cable leads to coil leads by trimming to proper length; strip off insulation and Formvar material on coil leads. It is wise to wrap a non-lint towel around the coil just below the terminating point and drape towel over mold to prevent bits of Formvar, insulation, solder, etc., from falling into mold. Connect leads together with solder. Shrink tubing makes a good insulation over solder joints. When termination is finished, remove toweling and install 6-in. extensions in place of $\frac{1}{2}$-in. extensions in mold. Duct Seal Compound may be used to seal area around extension and top of mold, and also full length of both extension seams. After plastic bottle filled with distilled water and sealed (Fig. 13) is seated, check the coil alignment; it must be centered properly. Pour the remainder of the material slowly over top of bottle. Try to avoid folding in any air; let material run down over sides of coil and fill from bottom up. When there is about one inch of material in bottom, stop pouring and wait a few minutes, using heat gun to break visual bubbles, then repeat the process. A total of 2190 grams was used on second pour (3 batches of 630 grams each with one batch of 300 grams). Pour all remaining material in same manner as prescribed above. Stop pouring when material has reached to within $\frac{1}{8}$ in. from top of extension.

Observe material every few minutes; if bubbles appear, use heat gun and repeat operation until material starts to gel. Let stand overnight before attempting to remove from mold. Next day remove from mold and place finished bottle in 110° (do not exceed this temperature) oven for eight or ten hours. The bottle should stand on its face, with the cable tied in an upright position until fully cured. If cable is not secured in upright position while curing, the material will cure in a bent position (Fig. 14). A total of 3450 grams was used to complete the encapsulation. A cutaway view of the complete magnetometer bottle is shown in Fig. 15, and the polyurethane encapsulated magnetometer bottle is shown in Fig. 16.

FIG. 14

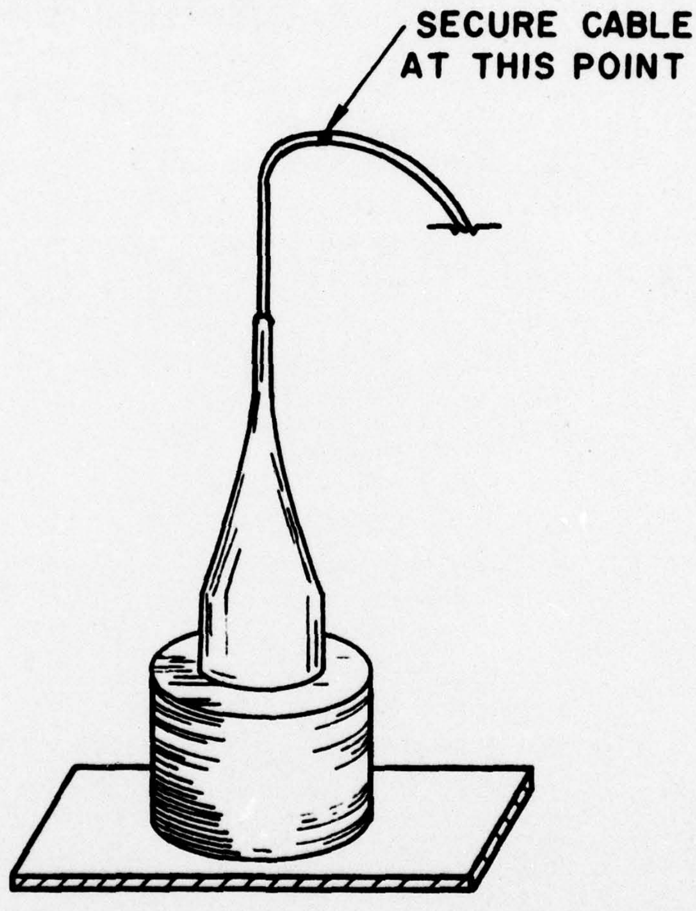


FIG. 15 COMPLETE BOTTLE

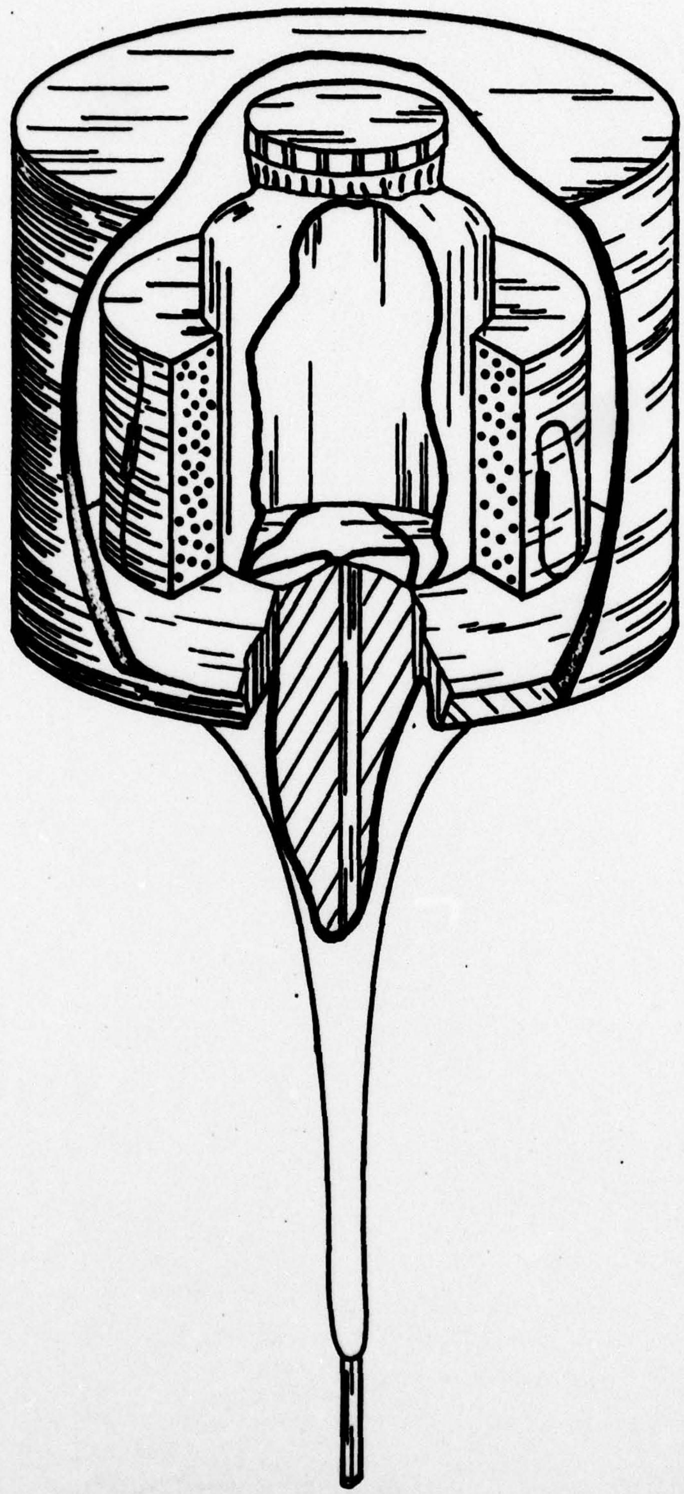


Fig. 15 A CUTAWAY VIEW OF THE COMPLETE MAGNETOMETER BOTTLE

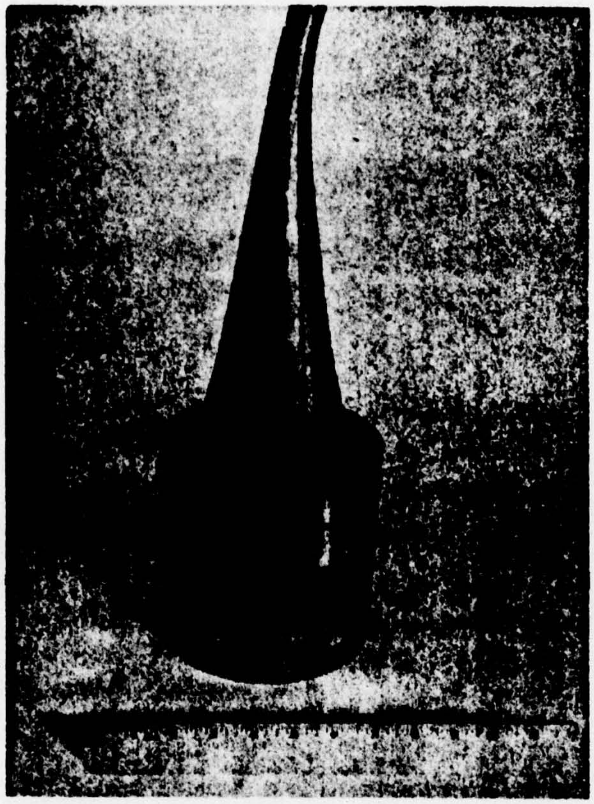


Fig. 16   MAGNETOMETER BOTTLE